US008665290B2

(12) **United States Patent**
Sloan

(10) **Patent No.: US 8,665,290 B2**
(45) **Date of Patent: Mar. 4, 2014**

(54) **IMAGE-BASED SOURCE GAMUT ADJUSTMENT FOR COMPRESSION-TYPE GAMUT MAPPING ALGORITHM**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 925 days.

(21) Appl. No.: **12/474,272**

(22) Filed: **May 28, 2009**

(65) **Prior Publication Data**

US 2010/0302271 A1 Dec. 2, 2010

(51) **Int. Cl.**
G09G 5/02 (2006.01)

(52) **U.S. Cl.**
USPC **345/590**; 345/589; 345/604; 382/165; 382/167; 382/168; 382/170

(58) **Field of Classification Search**
USPC 345/590; 382/165, 167, 168, 170, 589, 382/604
See application file for complete search history.

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Primary Examiner — Xiao M. Wu
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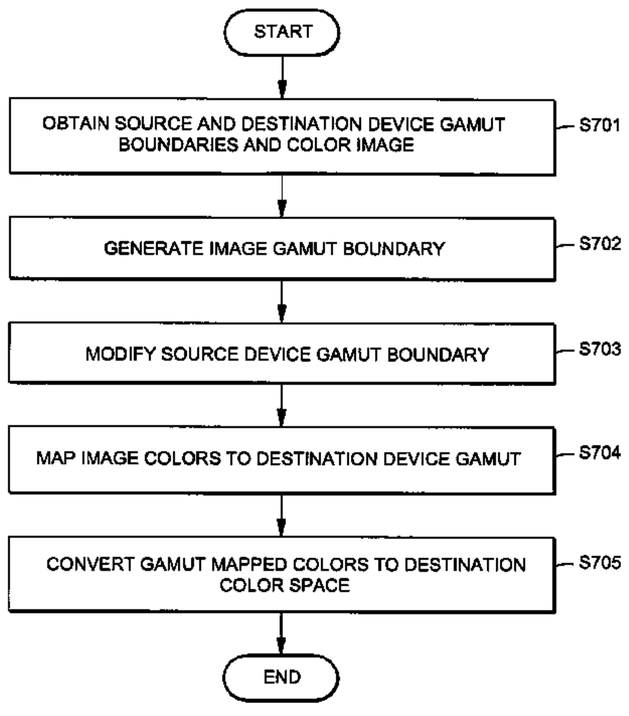
(74) *Attorney, Agent, or Firm* — Fitzpatrick, Cella, Harper & Scinto

(57) **ABSTRACT**

Color management which converts source device colors into counterpart colors in a destination device color space. Device independent source and destination device gamut boundaries are obtained. A color image is generated in the source device color space. The color image is transformed into an image in a device independent color space. A gamut boundary for the device independent image is generated, based on the content of the device independent image. The source device gamut boundary is shrunk in a hue symmetric manner, such that color hues do not change, until it touches the image gamut boundary. Colors of the device independent image are mapped onto a gamut of the destination device by invoking a compression-type gamut mapping algorithm that uses the modified source device gamut boundary and the destination device gamut boundary to perform gamut mapping. The gamut mapped colors are converted into colors in destination device dependent color space.

60 Claims, 18 Drawing Sheets



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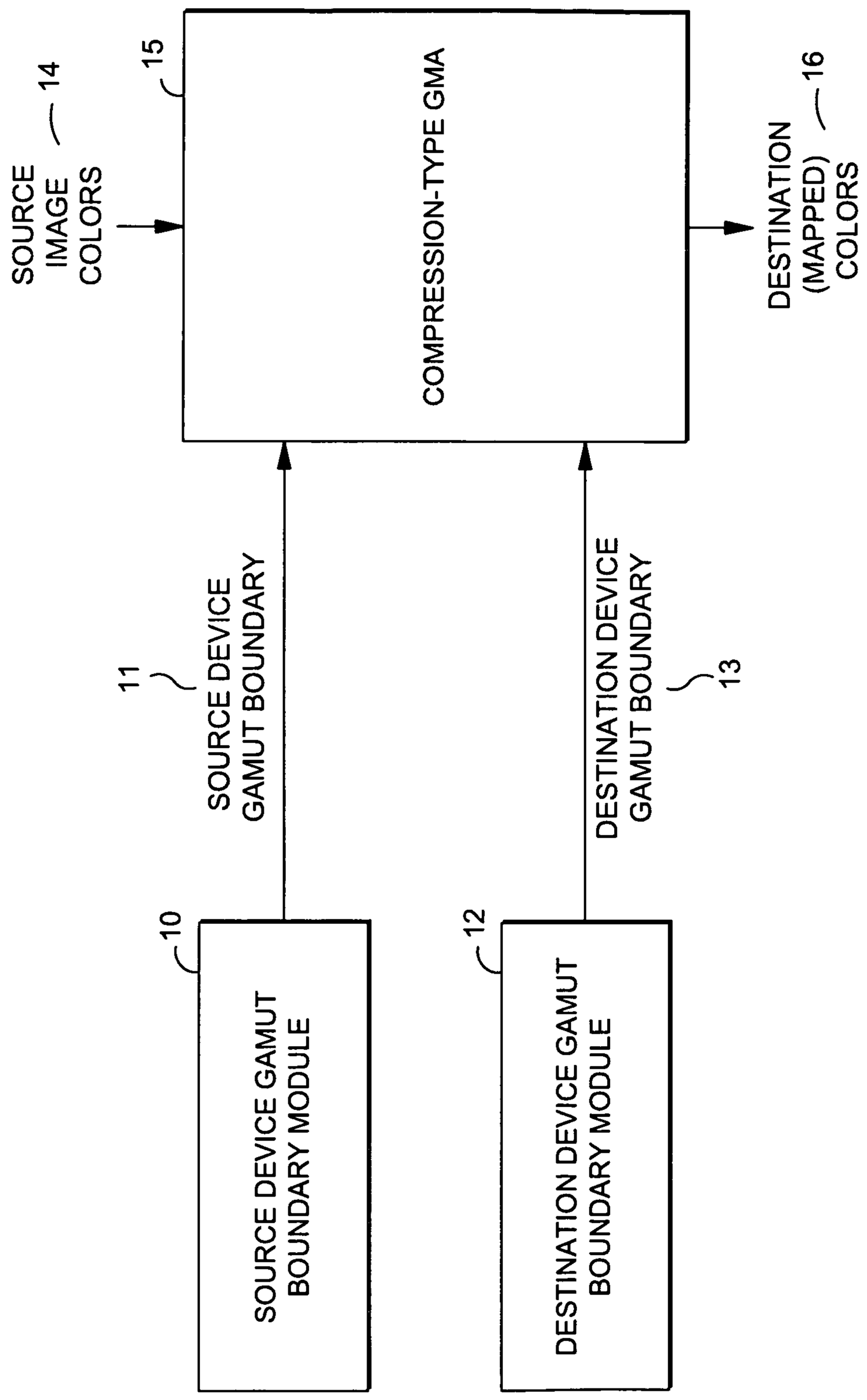

FIG. 1

PRIOR ART

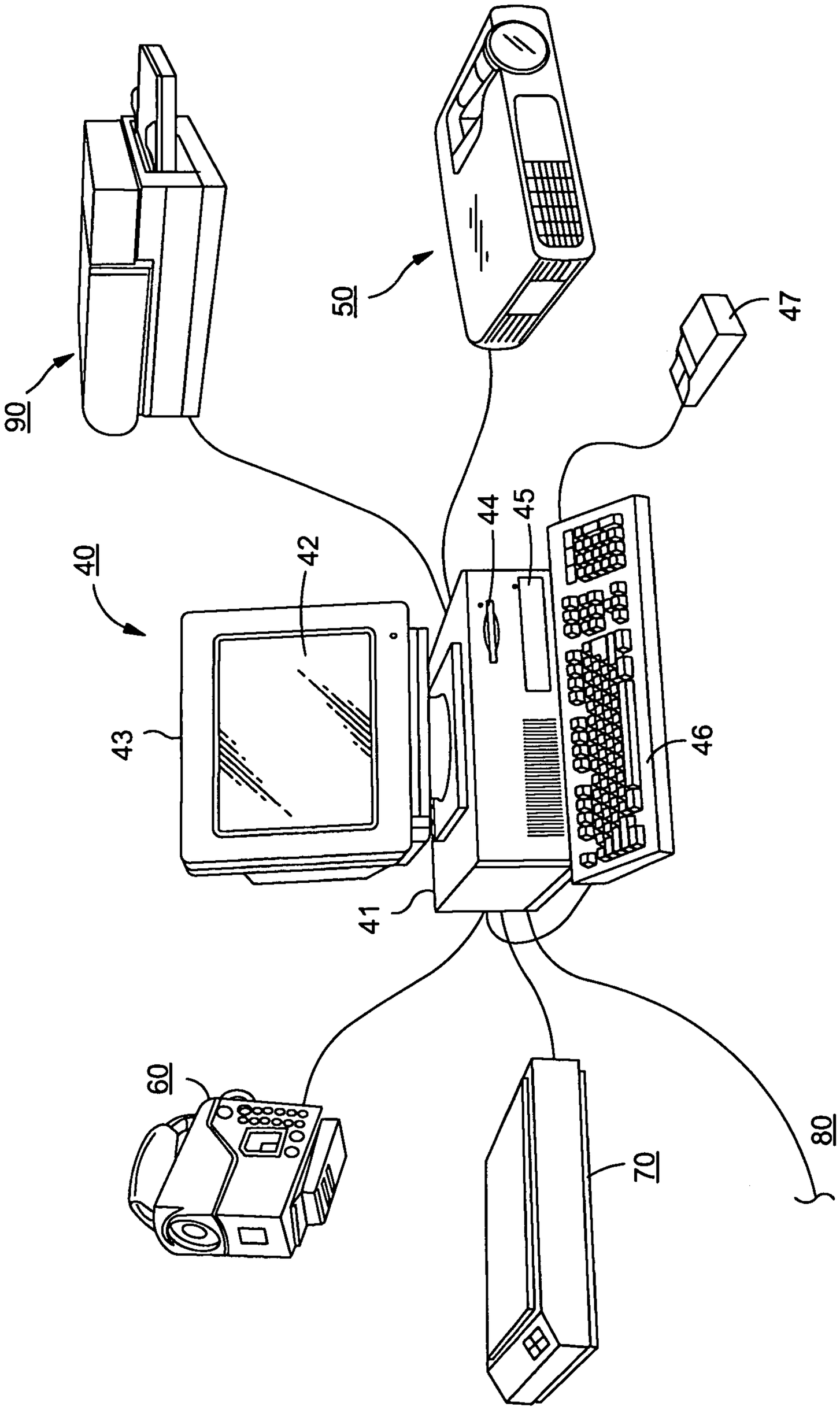

FIG. 2

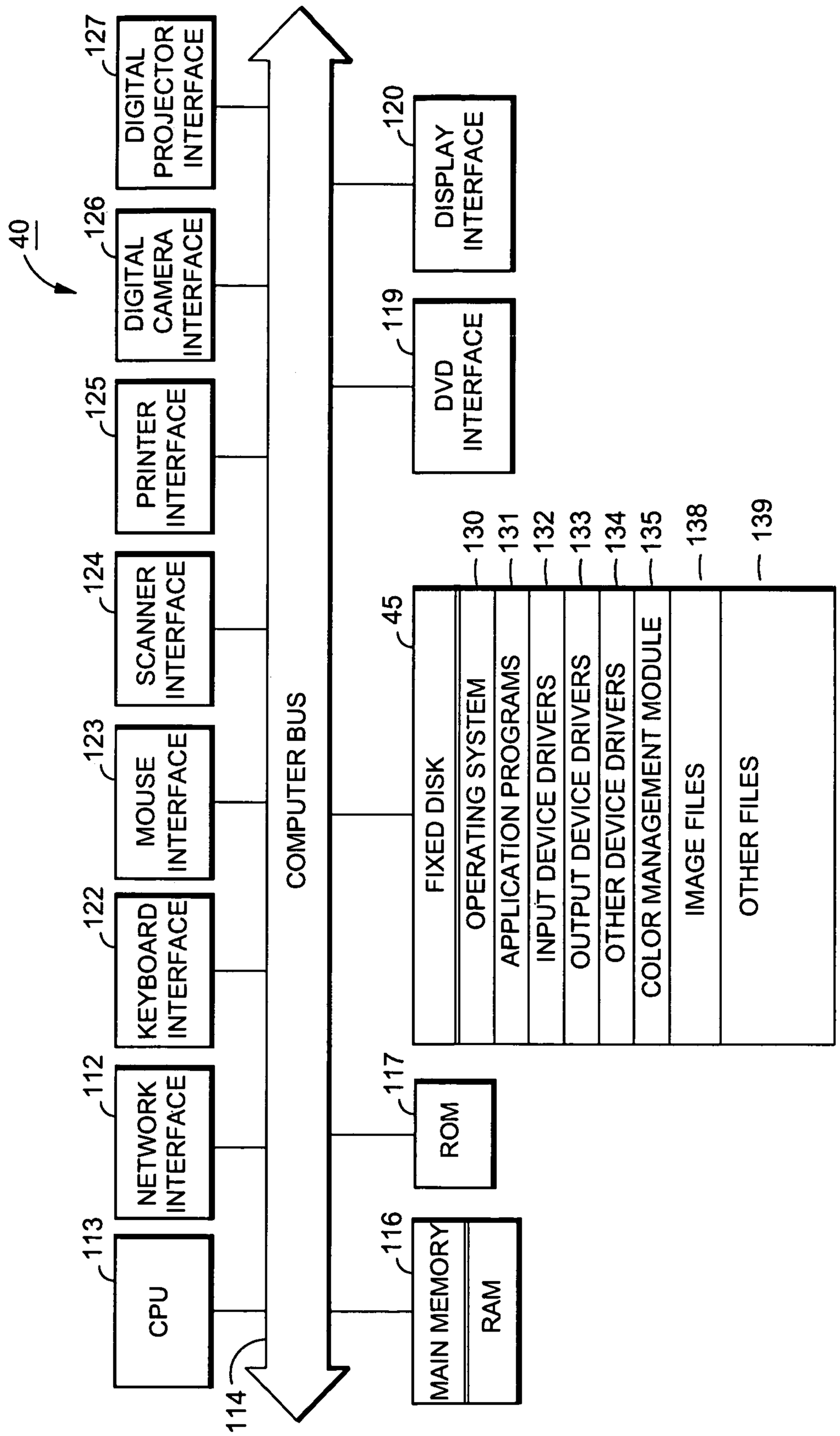
40
127
DIGITAL PROJECTOR INTERFACE
126
DIGITAL CAMERA INTERFACE
125
PRINTER INTERFACE
124
SCANNER INTERFACE
123
MOUSE INTERFACE
122
KEYBOARD INTERFACE
COMPUTER BUS
120
DISPLAY INTERFACE
119
DVD INTERFACE
45
FIXED DISK
130
OPERATING SYSTEM
131
APPLICATION PROGRAMS
132
INPUT DEVICE DRIVERS
133
OUTPUT DEVICE DRIVERS
134
OTHER DEVICE DRIVERS
135
COLOR MANAGEMENT MODULE
138
IMAGE FILES
139
OTHER FILES
117
ROM
116
MAIN MEMORY
RAM
112
NETWORK INTERFACE
113
CPU
114

FIG. 3

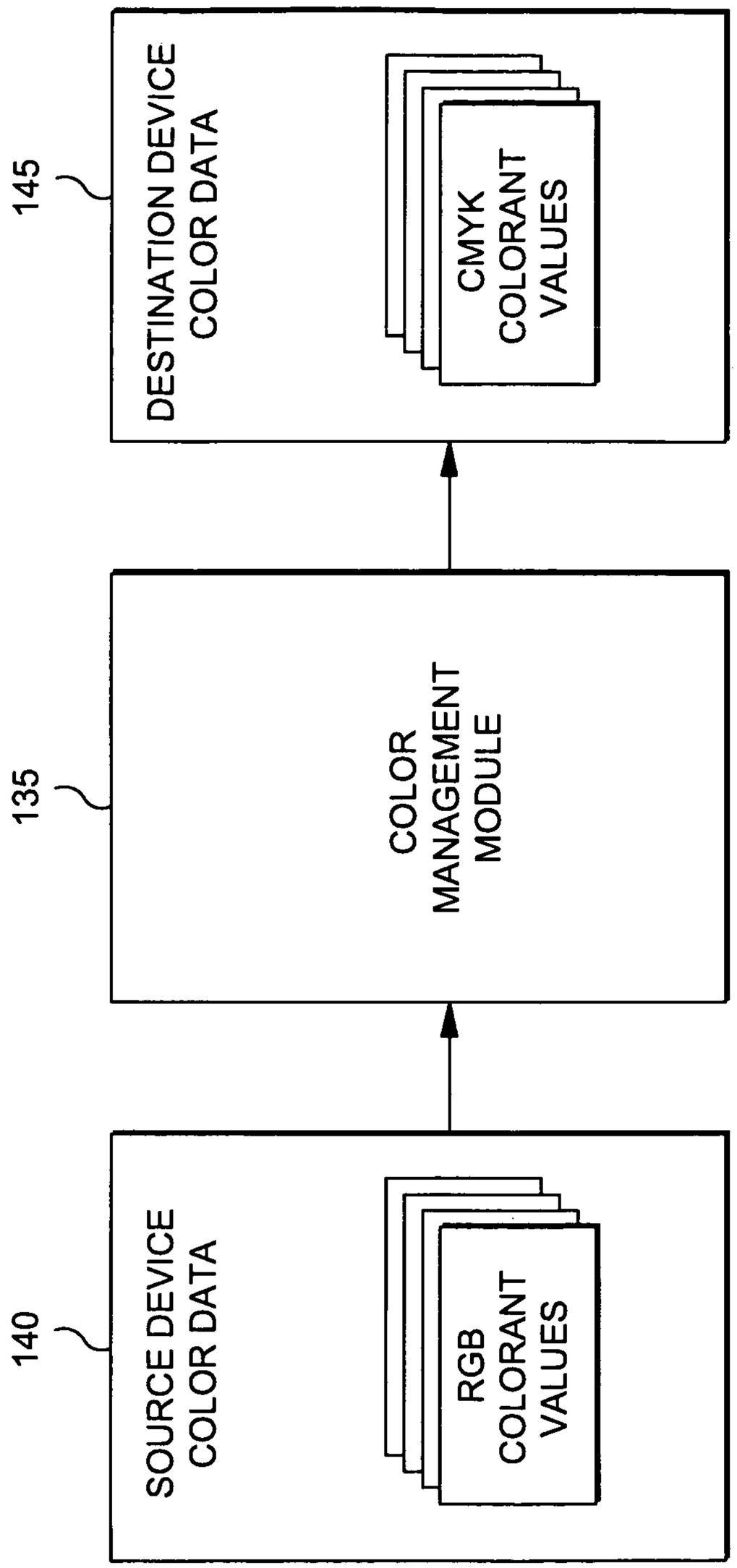
145
DESTINATION DEVICE COLOR DATA
CMYK COLORANT VALUES
135
COLOR MANAGEMENT MODULE
140
SOURCE DEVICE COLOR DATA
RGB COLORANT VALUES

FIG. 4

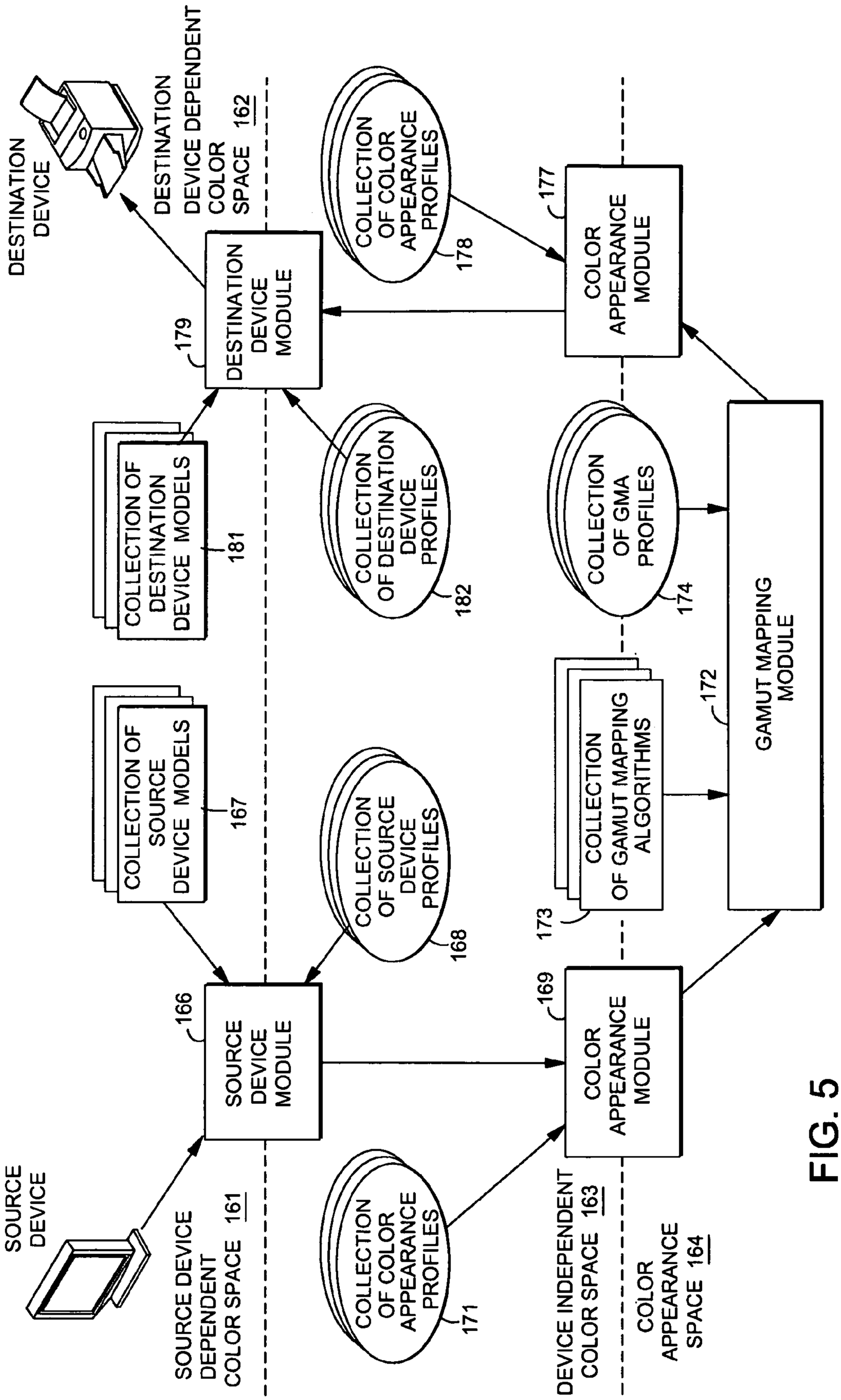
SOURCE DEVICE
SOURCE DEVICE DEPENDENT COLOR SPACE 161
SOURCE DEVICE MODULE
166
COLLECTION OF SOURCE DEVICE MODELS
167
COLLECTION OF SOURCE DEVICE PROFILES
168
COLLECTION OF COLOR APPEARANCE PROFILES
171
DESTINATION DEVICE
DESTINATION DEVICE DEPENDENT COLOR SPACE 162
DESTINATION DEVICE MODULE
179
COLLECTION OF DESTINATION DEVICE MODELS
181
COLLECTION OF DESTINATION DEVICE PROFILES
182
COLLECTION OF COLOR APPEARANCE PROFILES
178
COLOR APPEARANCE MODULE
177
DEVICE INDEPENDENT COLOR SPACE 163
COLOR APPEARANCE MODULE
169
COLOR APPEARANCE SPACE 164
COLLECTION OF GMA PROFILES
174
COLLECTION OF GAMUT MAPPING ALGORITHMS
173
GAMUT MAPPING MODULE
172

FIG. 5

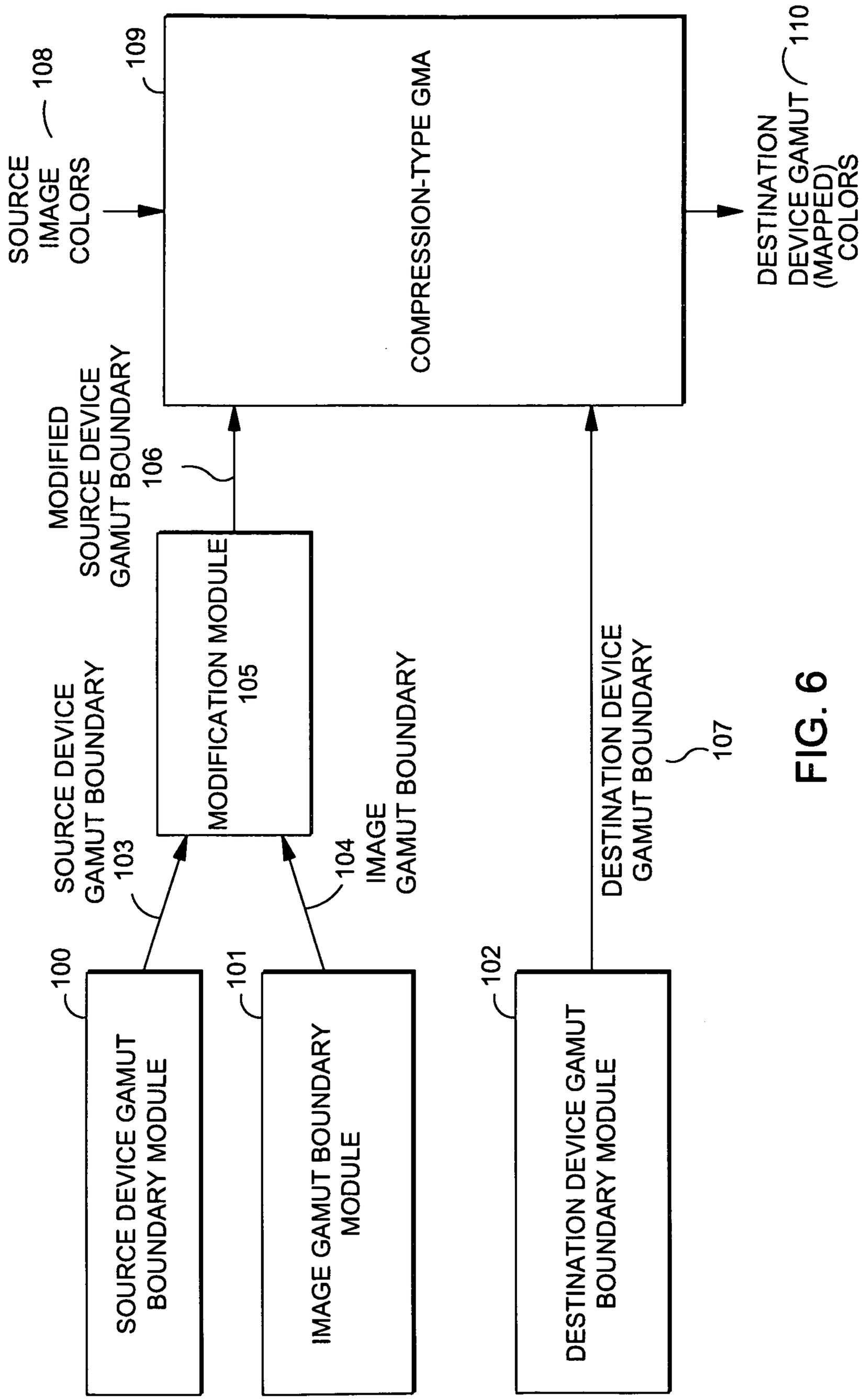
SOURCE IMAGE COLORS
108
109
COMPRESSION-TYPE GMA
DESTINATION DEVICE GAMUT (MAPPED) COLORS
110
MODIFIED SOURCE DEVICE GAMUT BOUNDARY
106
MODIFICATION MODULE
105
SOURCE DEVICE GAMUT BOUNDARY
103
IMAGE GAMUT BOUNDARY
104
DESTINATION DEVICE GAMUT BOUNDARY
107
100
SOURCE DEVICE GAMUT BOUNDARY MODULE
101
IMAGE GAMUT BOUNDARY MODULE
102
DESTINATION DEVICE GAMUT BOUNDARY MODULE

FIG. 6

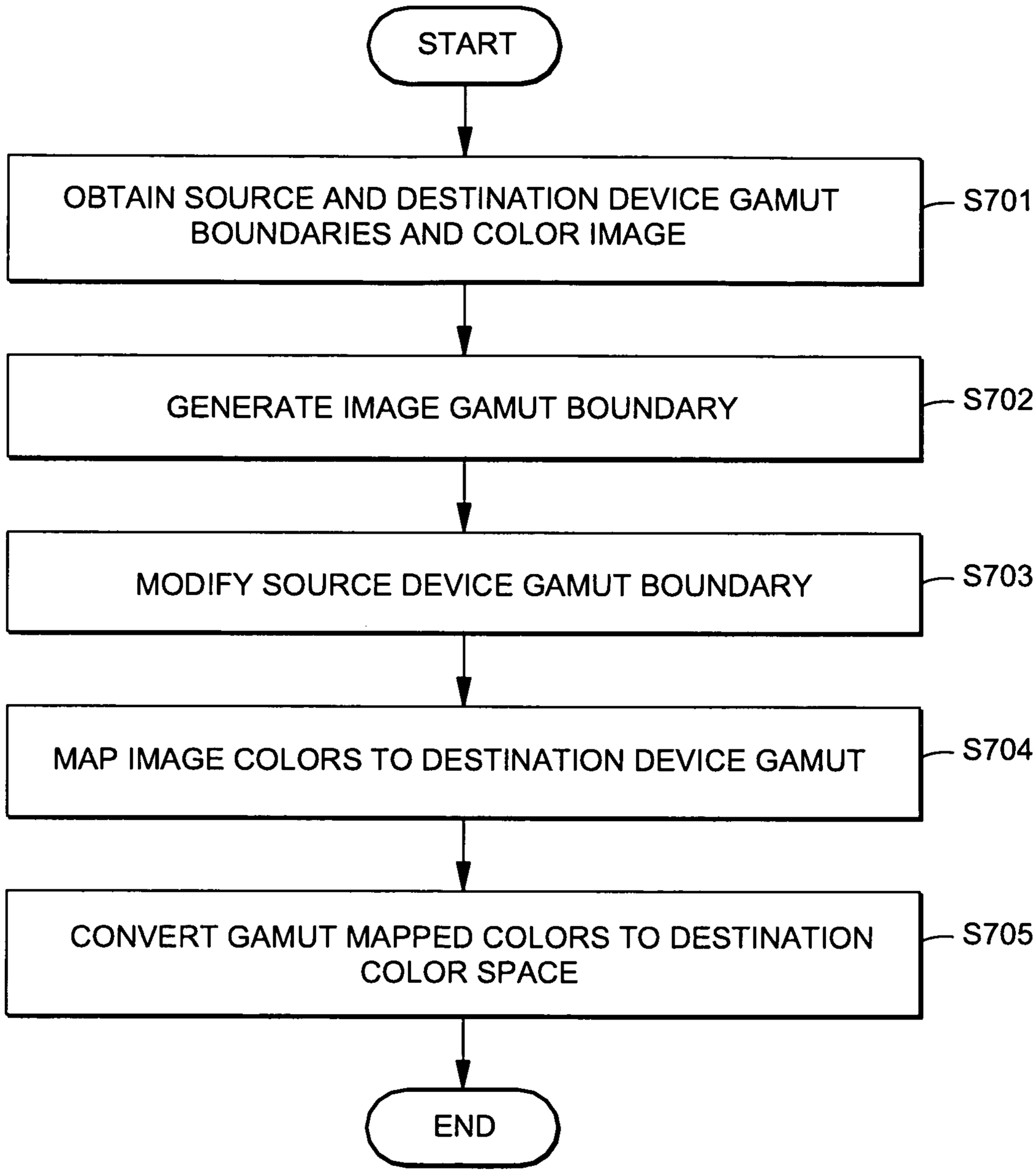
START
OBTAIN SOURCE AND DESTINATION DEVICE GAMUT BOUNDARIES AND COLOR IMAGE
S701
GENERATE IMAGE GAMUT BOUNDARY
S702
MODIFY SOURCE DEVICE GAMUT BOUNDARY
S703
MAP IMAGE COLORS TO DESTINATION DEVICE GAMUT
S704
CONVERT GAMUT MAPPED COLORS TO DESTINATION COLOR SPACE
S705
END

FIG. 7

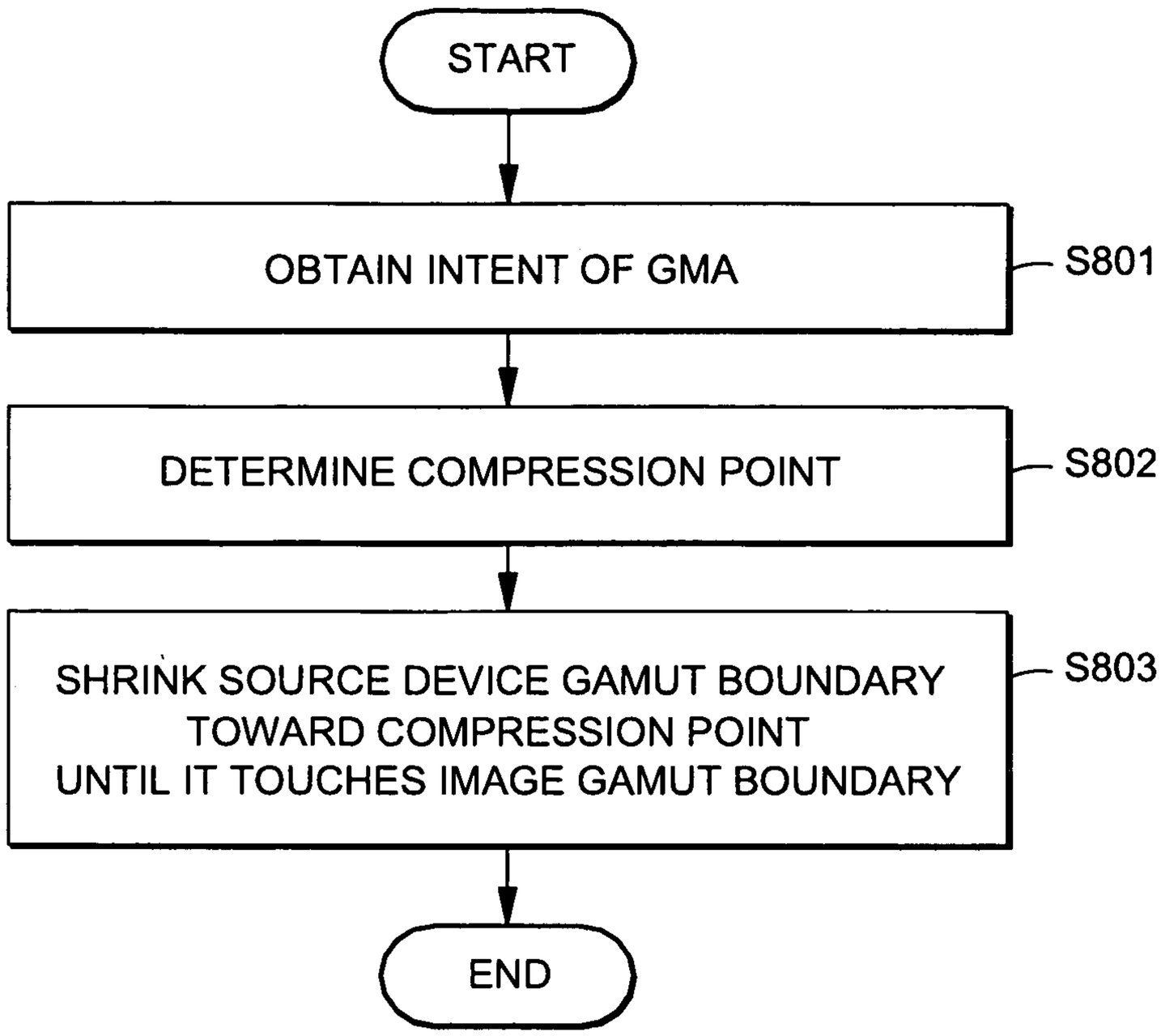
START
OBTAIN INTENT OF GMA
S801
DETERMINE COMPRESSION POINT
S802
SHRINK SOURCE DEVICE GAMUT BOUNDARY TOWARD COMPRESSION POINT UNTIL IT TOUCHES IMAGE GAMUT BOUNDARY
S803
END

FIG. 8

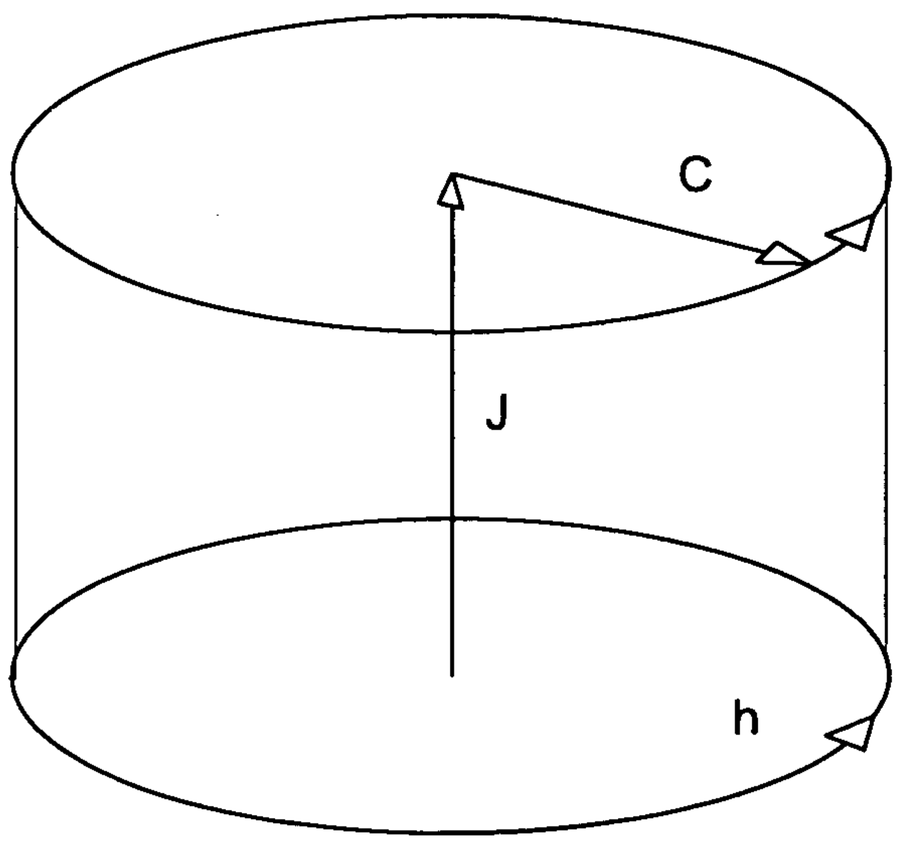
C
J
h

FIG. 9

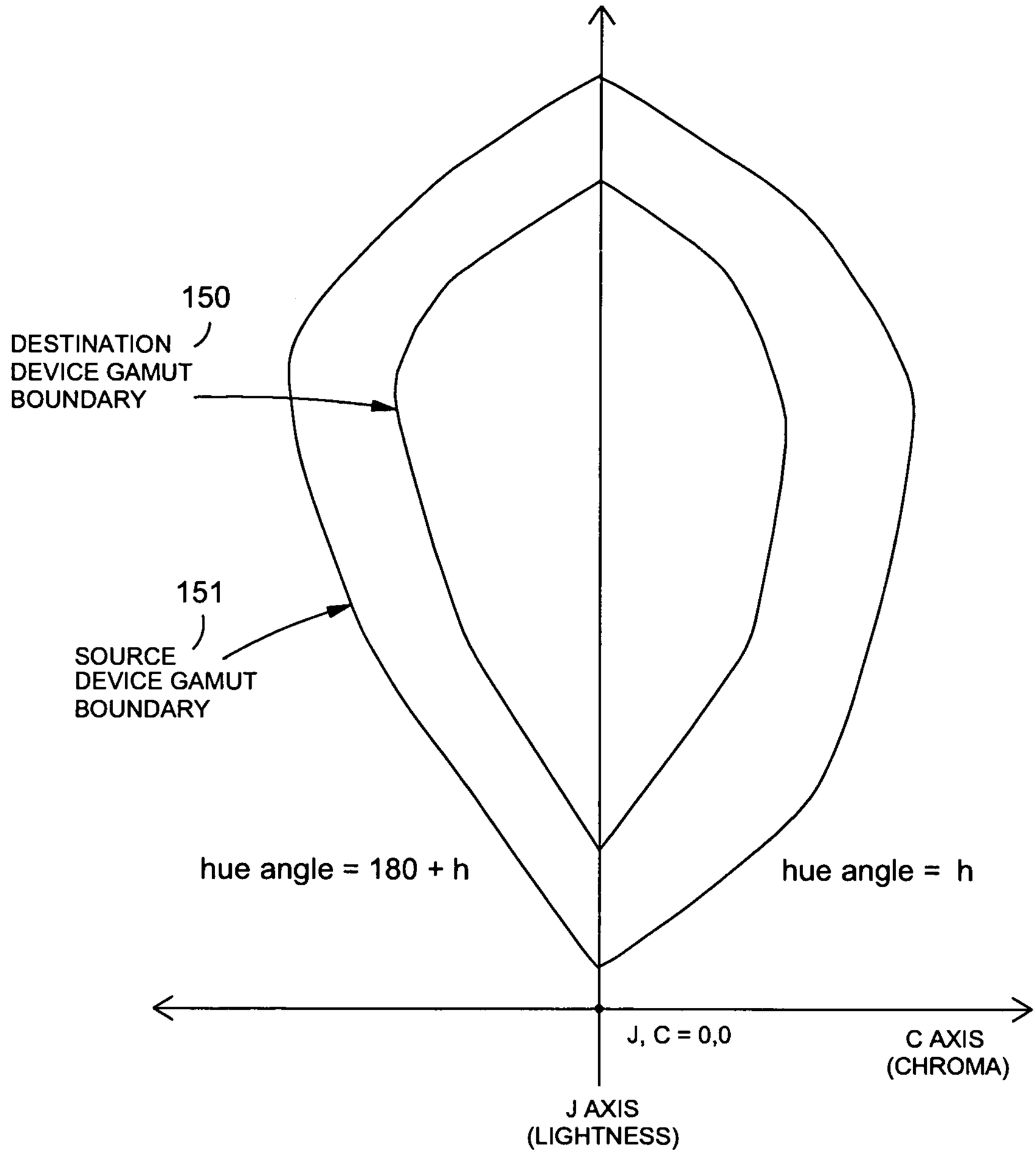
150
DESTINATION DEVICE GAMUT BOUNDARY
151
SOURCE DEVICE GAMUT BOUNDARY
hue angle = 180 + h
hue angle = h
J, C = 0,0
C AXIS (CHROMA)
J AXIS (LIGHTNESS)

FIG. 10

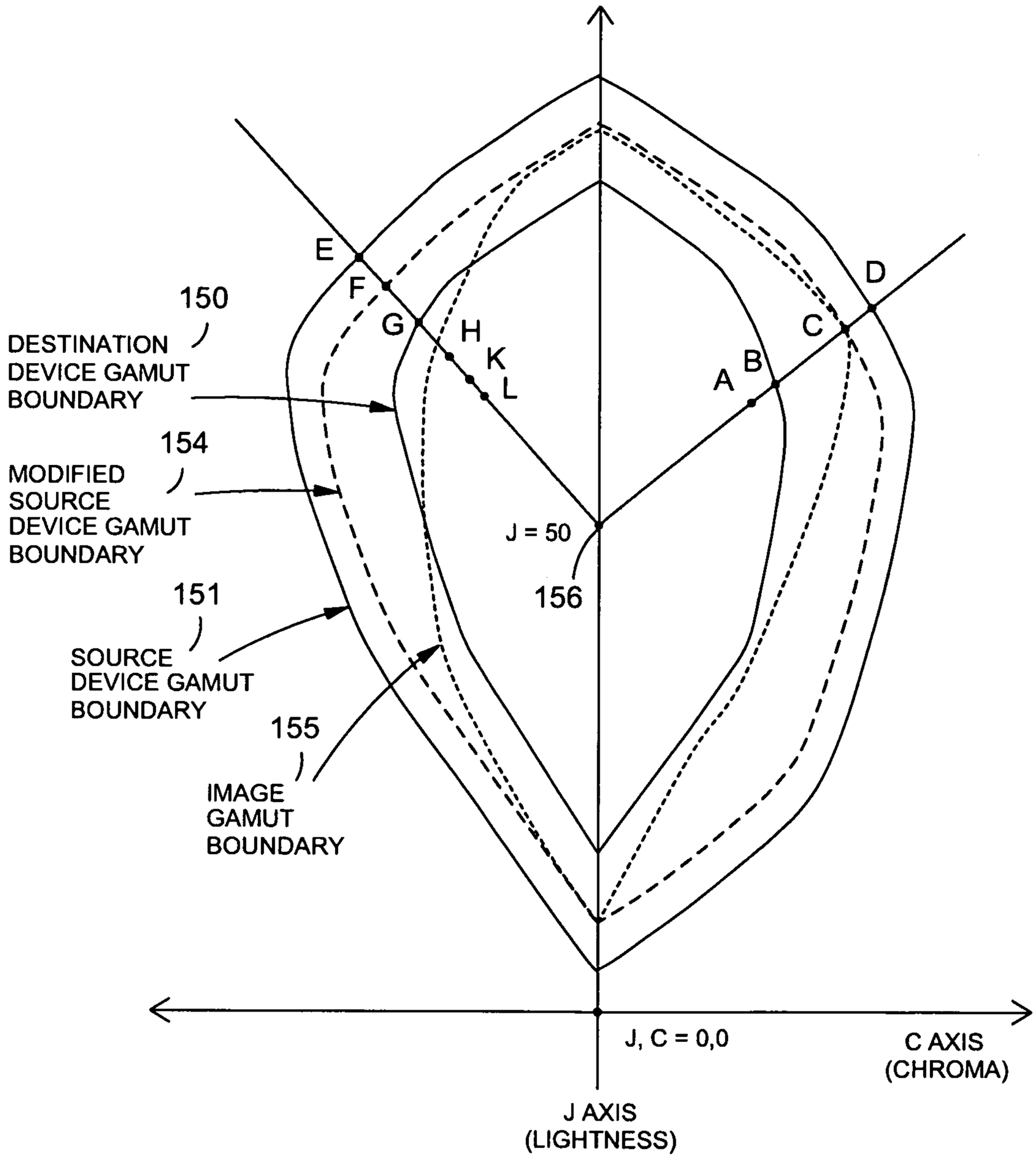
E
F
G
H
K
L
A
B
C
D
J = 50
156
150
DESTINATION DEVICE GAMUT BOUNDARY
154
MODIFIED SOURCE DEVICE GAMUT BOUNDARY
151
SOURCE DEVICE GAMUT BOUNDARY
155
IMAGE GAMUT BOUNDARY
J, C = 0,0
C AXIS (CHROMA)
J AXIS (LIGHTNESS)

FIG. 11

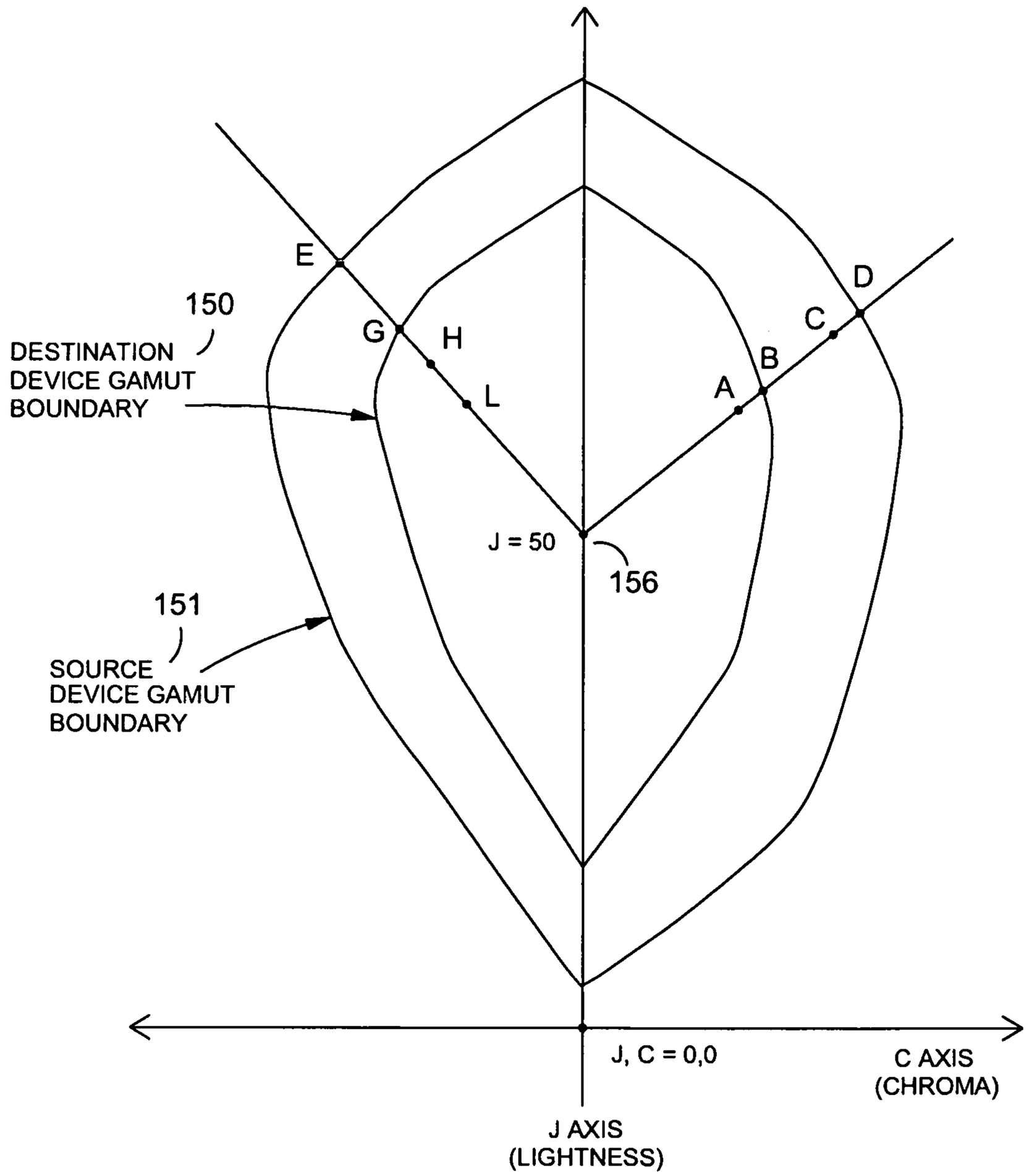
E
D
150
C
G
H
B
DESTINATION
DEVICE GAMUT
BOUNDARY
L
A
J = 50
156
151
SOURCE
DEVICE GAMUT
BOUNDARY
J, C = 0,0
C AXIS
(CHROMA)
J AXIS
(LIGHTNESS)

FIG. 12

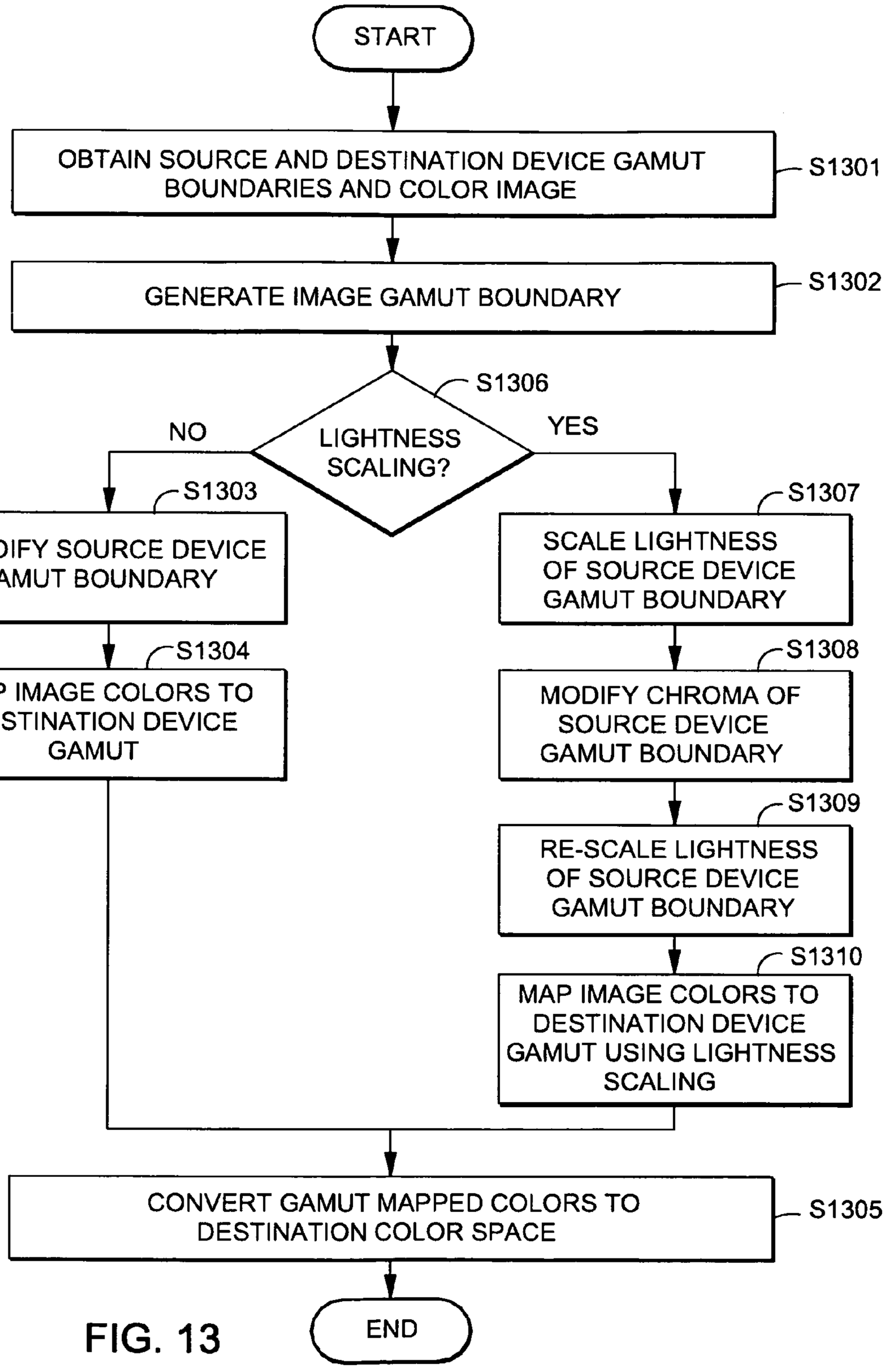
START
OBTAIN SOURCE AND DESTINATION DEVICE GAMUT BOUNDARIES AND COLOR IMAGE
S1301
GENERATE IMAGE GAMUT BOUNDARY
S1302
S1306
LIGHTNESS SCALING?
NO
YES
S1303
MODIFY SOURCE DEVICE GAMUT BOUNDARY
S1304
MAP IMAGE COLORS TO DESTINATION DEVICE GAMUT
S1307
SCALE LIGHTNESS OF SOURCE DEVICE GAMUT BOUNDARY
S1308
MODIFY CHROMA OF SOURCE DEVICE GAMUT BOUNDARY
S1309
RE-SCALE LIGHTNESS OF SOURCE DEVICE GAMUT BOUNDARY
S1310
MAP IMAGE COLORS TO DESTINATION DEVICE GAMUT USING LIGHTNESS SCALING
CONVERT GAMUT MAPPED COLORS TO DESTINATION COLOR SPACE
S1305
END

FIG. 13

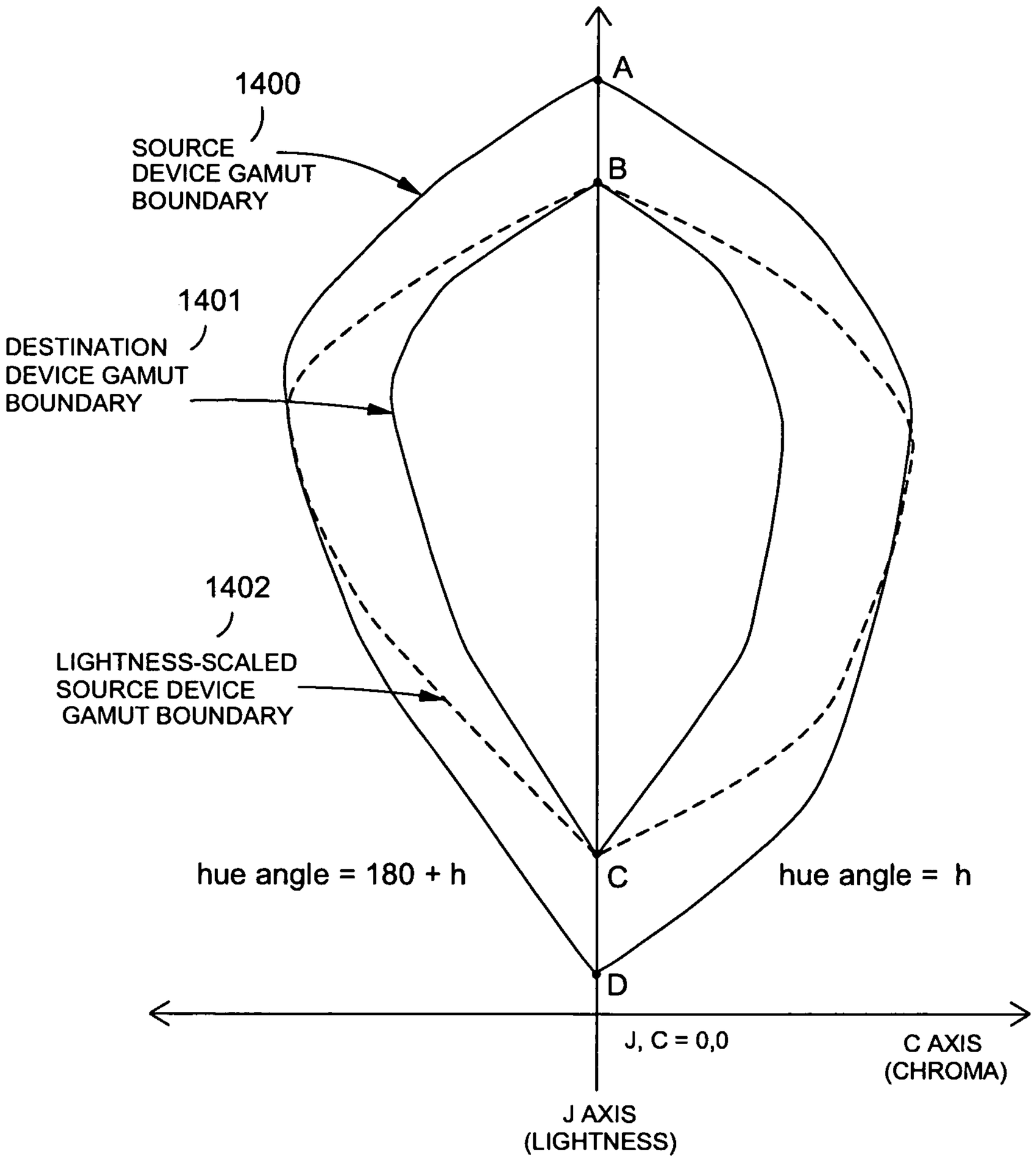
1400
SOURCE DEVICE GAMUT BOUNDARY
1401
DESTINATION DEVICE GAMUT BOUNDARY
1402
LIGHTNESS-SCALED SOURCE DEVICE GAMUT BOUNDARY
A
B
C
D
hue angle = 180 + h
hue angle = h
J, C = 0,0
C AXIS (CHROMA)
J AXIS (LIGHTNESS)

FIG. 14

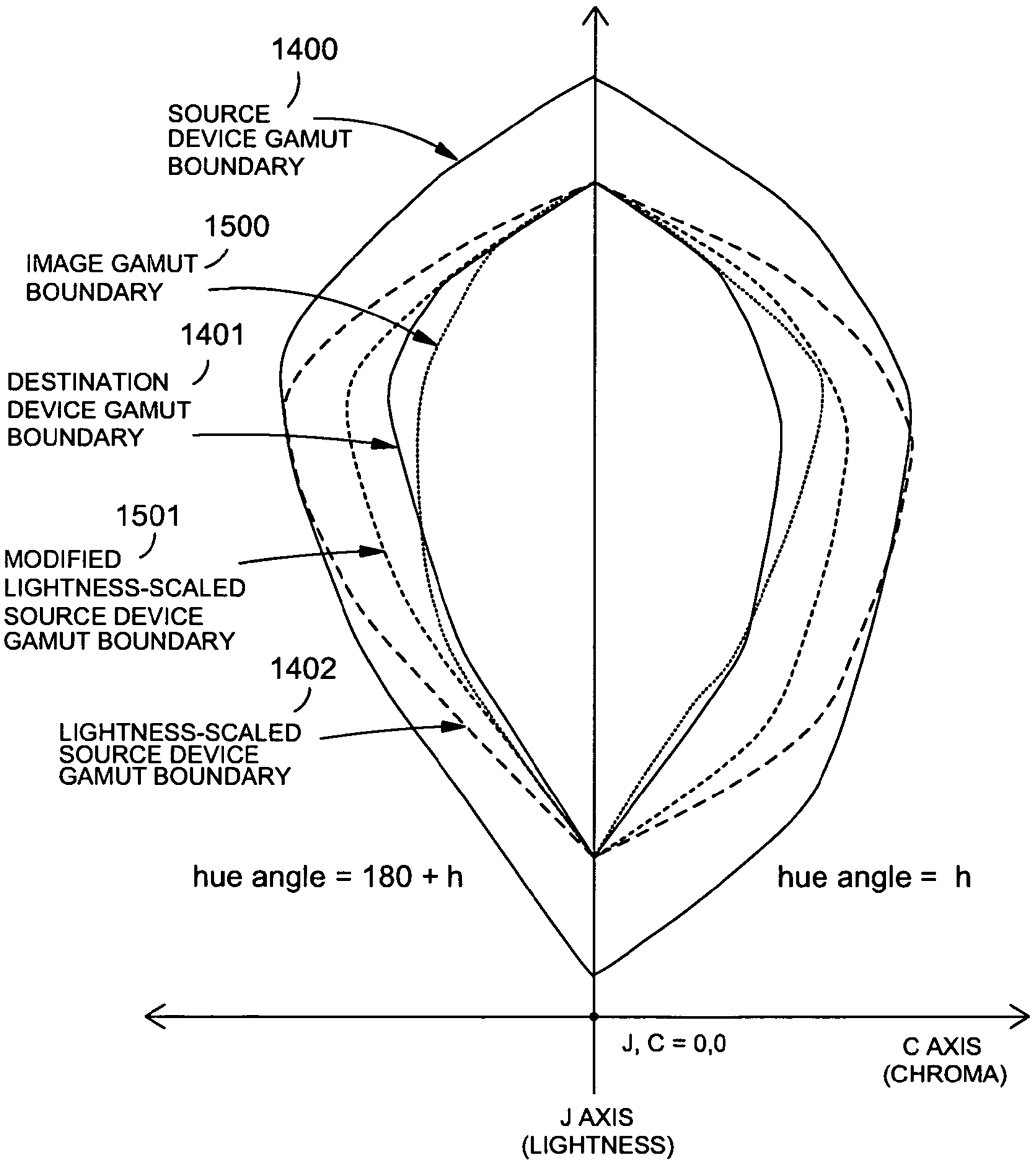
1400
SOURCE DEVICE GAMUT BOUNDARY
1500
IMAGE GAMUT BOUNDARY
1401
DESTINATION DEVICE GAMUT BOUNDARY
1501
MODIFIED LIGHTNESS-SCALED SOURCE DEVICE GAMUT BOUNDARY
1402
LIGHTNESS-SCALED SOURCE DEVICE GAMUT BOUNDARY
hue angle = 180 + h
hue angle = h
J, C = 0,0
C AXIS (CHROMA)
J AXIS (LIGHTNESS)

FIG. 15

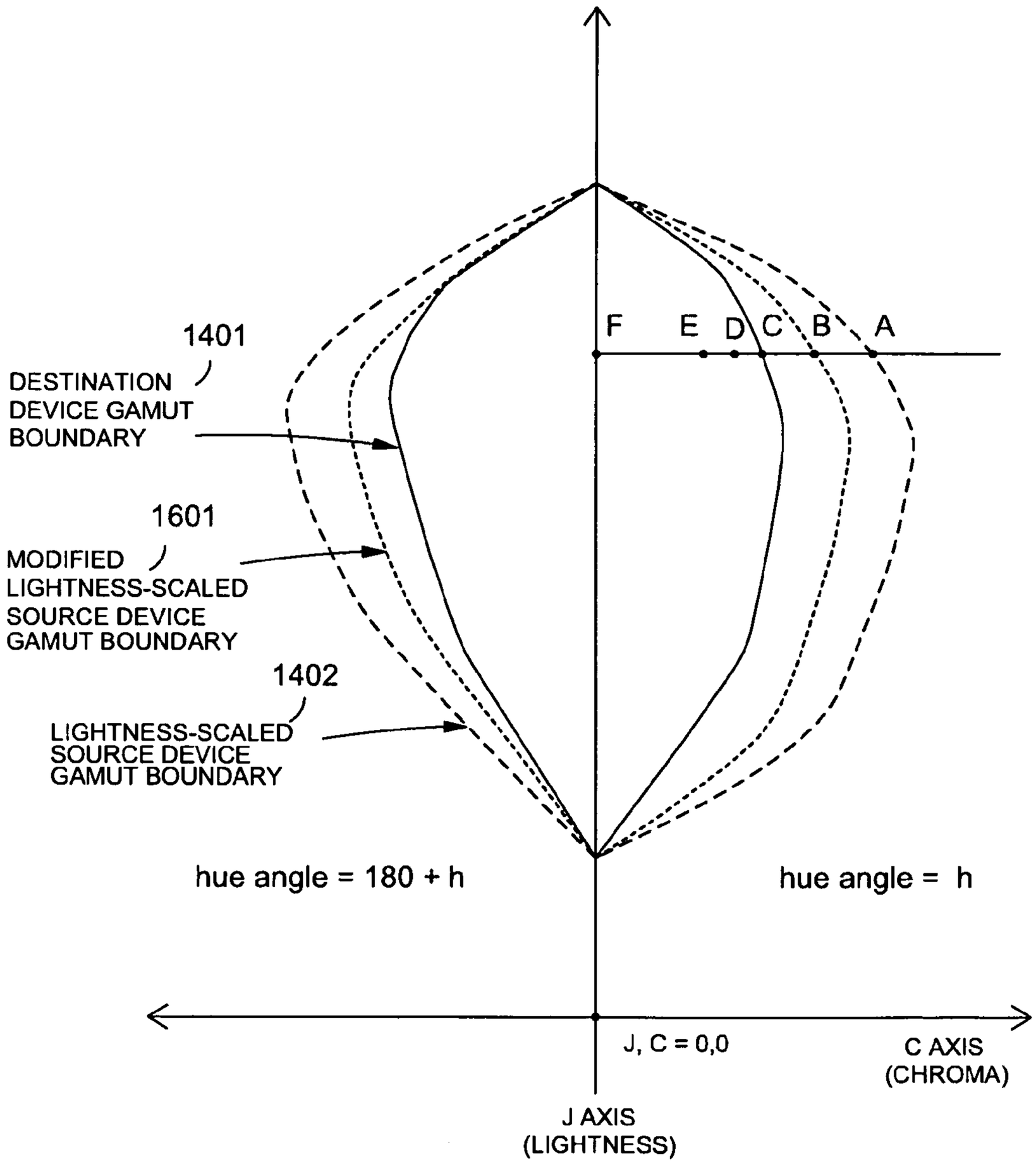
1401
DESTINATION DEVICE GAMUT BOUNDARY
1601
MODIFIED LIGHTNESS-SCALED SOURCE DEVICE GAMUT BOUNDARY
1402
LIGHTNESS-SCALED SOURCE DEVICE GAMUT BOUNDARY
F
E
D
C
B
A
hue angle = 180 + h
hue angle = h
J, C = 0,0
C AXIS (CHROMA)
J AXIS (LIGHTNESS)

FIG. 16

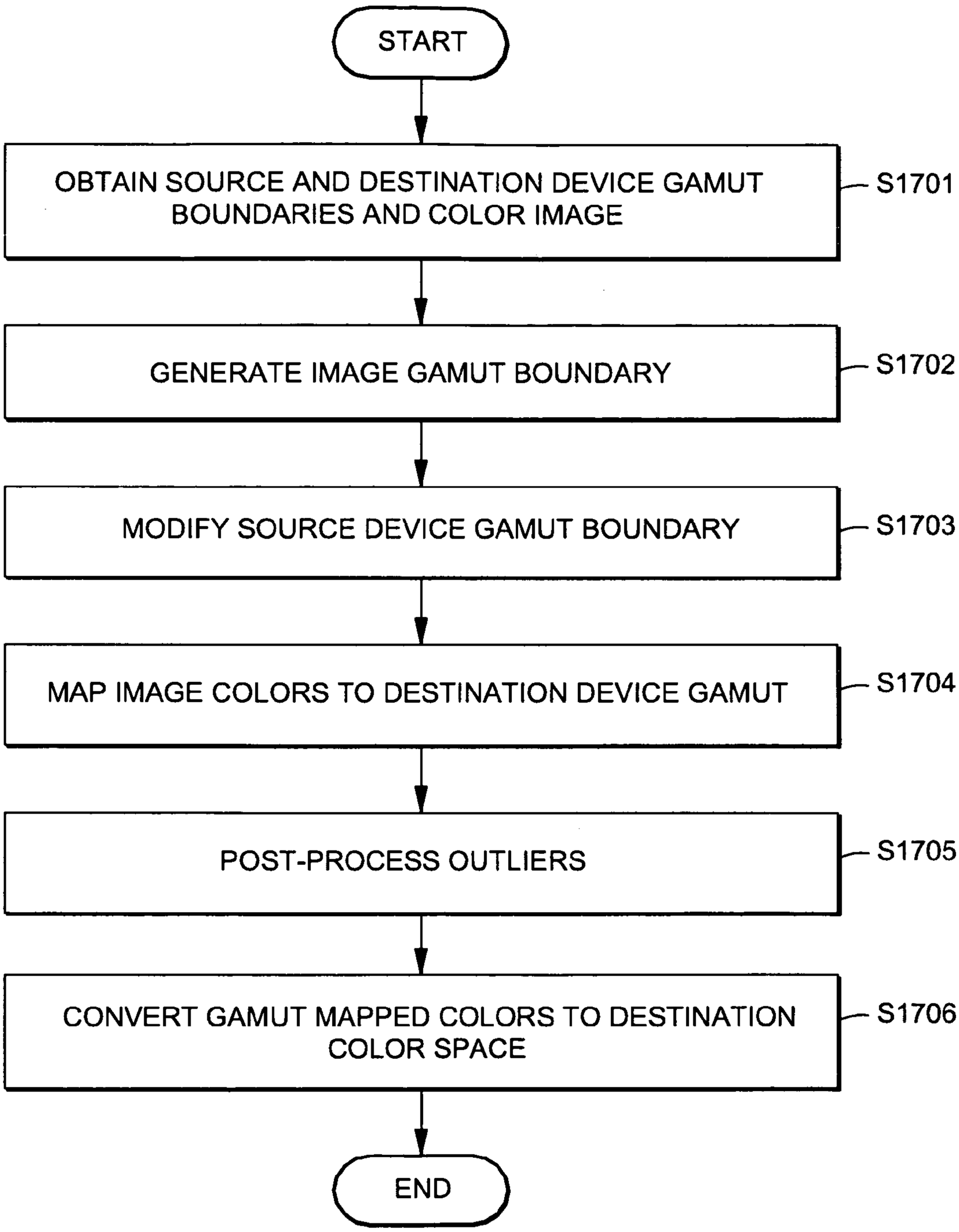
START
OBTAIN SOURCE AND DESTINATION DEVICE GAMUT BOUNDARIES AND COLOR IMAGE
S1701
GENERATE IMAGE GAMUT BOUNDARY
S1702
MODIFY SOURCE DEVICE GAMUT BOUNDARY
S1703
MAP IMAGE COLORS TO DESTINATION DEVICE GAMUT
S1704
POST-PROCESS OUTLIERS
S1705
CONVERT GAMUT MAPPED COLORS TO DESTINATION COLOR SPACE
S1706
END

FIG. 17

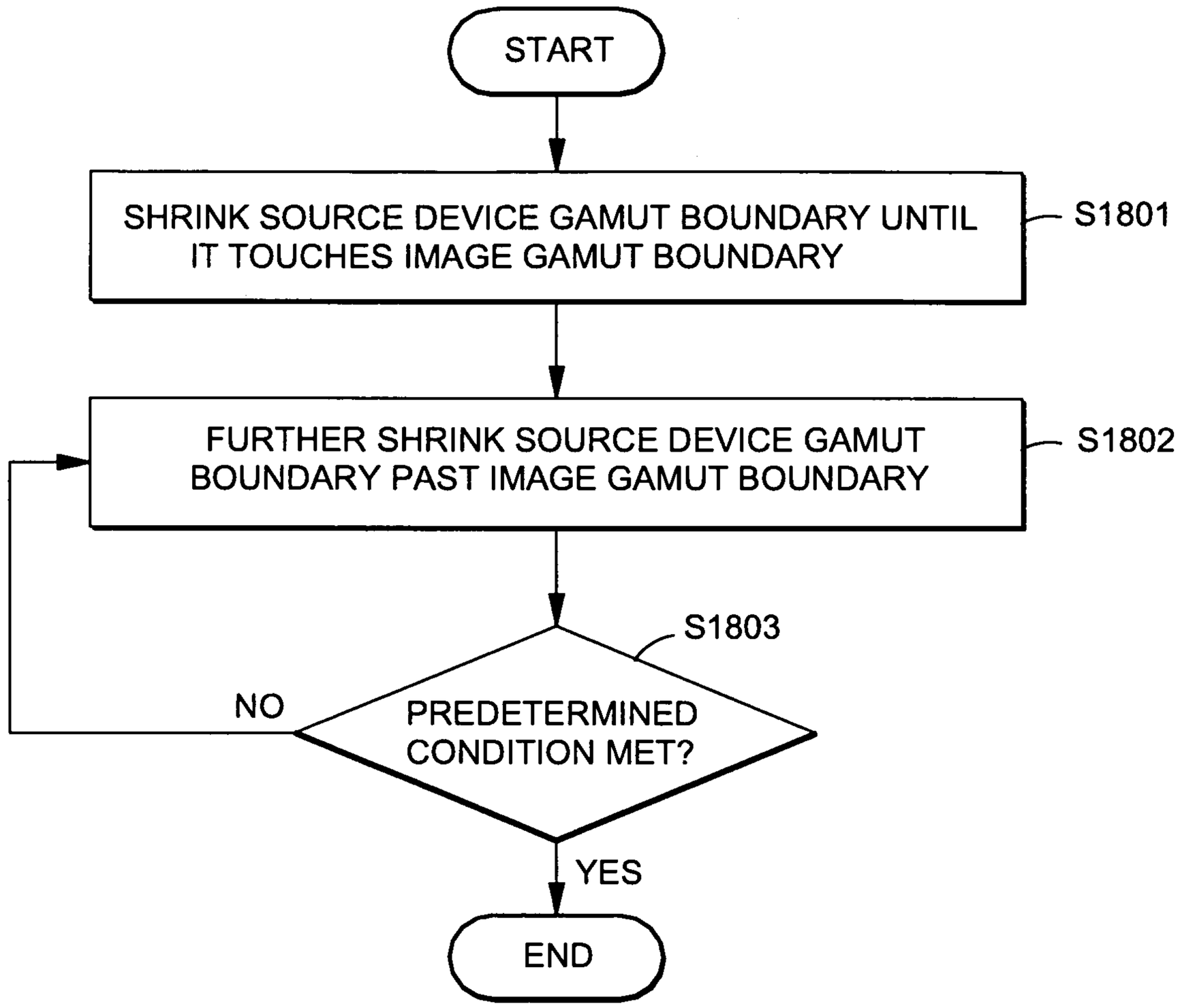
START
SHRINK SOURCE DEVICE GAMUT BOUNDARY UNTIL IT TOUCHES IMAGE GAMUT BOUNDARY
S1801
FURTHER SHRINK SOURCE DEVICE GAMUT BOUNDARY PAST IMAGE GAMUT BOUNDARY
S1802
S1803
PREDETERMINED CONDITION MET?
NO
YES
END

FIG. 18

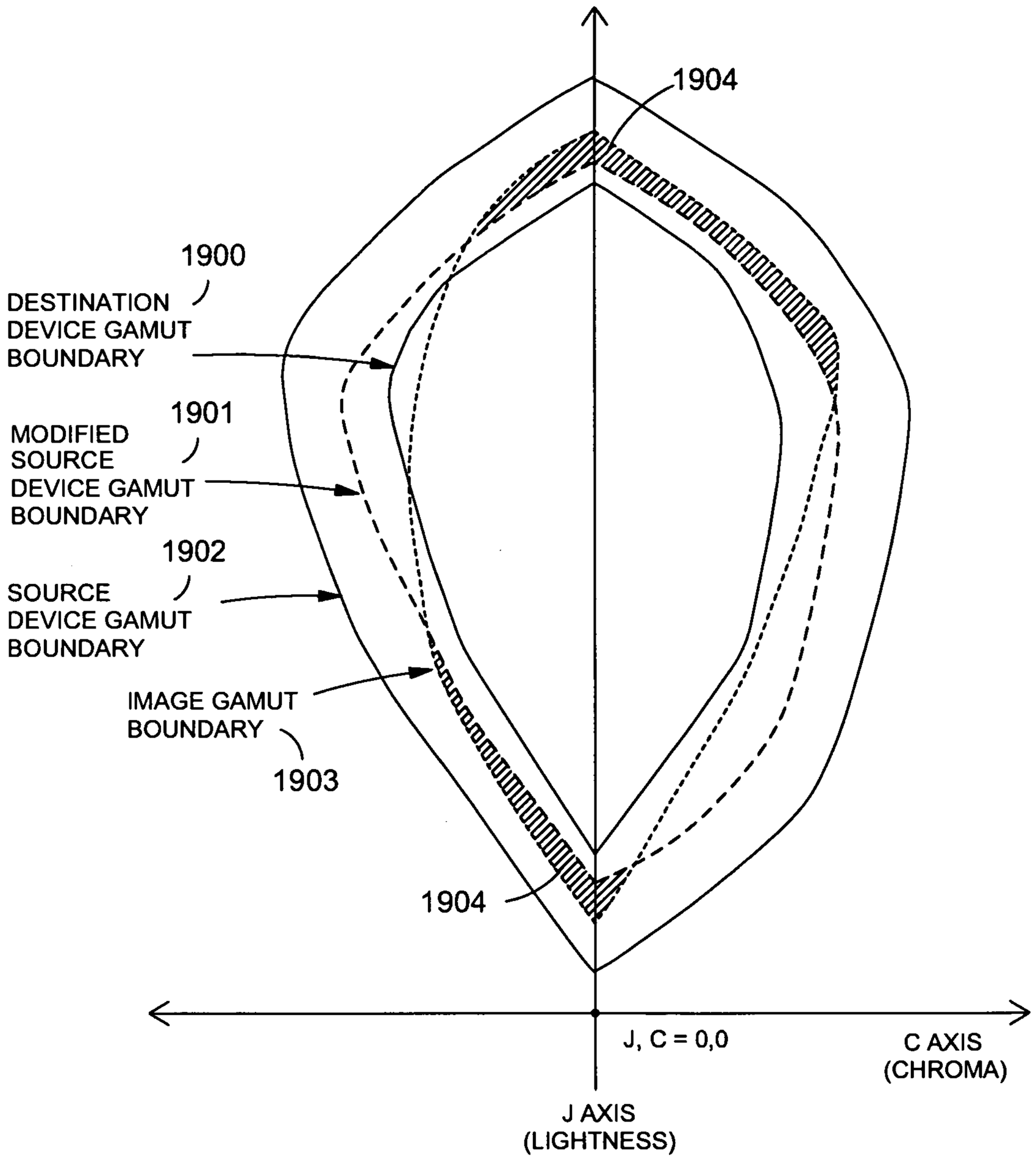
1904
1900
DESTINATION DEVICE GAMUT BOUNDARY
1901
MODIFIED SOURCE DEVICE GAMUT BOUNDARY
1902
SOURCE DEVICE GAMUT BOUNDARY
IMAGE GAMUT BOUNDARY
1903
1904
J, C = 0,0
C AXIS (CHROMA)
J AXIS (LIGHTNESS)

FIG. 19

IMAGE-BASED SOURCE GAMUT ADJUSTMENT FOR COMPRESSION-TYPE GAMUT MAPPING ALGORITHM

FIELD OF THE INVENTION

The present disclosure relates to color management systems, and more particularly relates to color management systems that use compression-type gamut mapping algorithms.

BACKGROUND

Color management systems (CMS) perform gamut mapping to convert color between color device representations of a source and a destination color device. To perform this conversion, color values for a color space of the source device are converted into color values for a device independent color space, and thereafter, these device-independent color values are converted into values for a color space of the destination device.

Because a source device (e.g., a digital camera) and a destination device (e.g., a printer) typically have different color gamuts with respect to each other, a gamut mismatch may occur, meaning that some colors within the source device's color space may not be represented within the destination device's color space. Often, a destination device gamut is smaller than the source device gamut because the source device is capable of producing more colors than the destination device. To achieve an intended reproduction of source colors on the destination device, gamut mapping is performed.

Gamut mapping is the process of mapping colors in the source device gamut onto the destination device gamut. Gamut mapping is often performed using a compression-type gamut mapping algorithm (GMA). Compression-type GMAs use source and destination device gamut boundaries to determine the amount of compression (movement) needed to map a color point in the source device gamut onto the destination device gamut. Examples of compression-type GMAs include midpoint compression, cusp point compression and knee point compression GMAs.

FIG. **1** shows a typical architecture for gamut mapping using a compression-type GMA. Source device gamut boundary **11** is created from a source device model by a source device gamut boundary module **10** and destination device gamut boundary **13** is created from a destination device model by destination device gamut boundary module **12**. Source device gamut boundary **11** and destination device gamut boundary **13**, together with source image colors **14**, are provided to compression-type GMA **15**. Compression-type GMA **15** is applied to source image colors **14** in order to map source image colors **14** to destination colors **16**, using source device gamut boundary **11** and destination device gamut boundary **13**.

Compression-type GMAs perform color conversion according to various color reproduction intents which define a desired relationship between the source and destination color values. The intent of the GMA dictates the direction and magnitude of compression. For example, a GMA can perform with an intent to maintain accuracy of the original image or with an intent to maximize pleasantness to a viewer. Often, compression-type GMAs preserve the details of an image. However if too much compression is performed, some of the colorfulness (i.e., chroma) of the image may be lost.

Other types of GMAs include image-based GMAs and clipping-type GMAs. Image-based GMAs use various image characteristics to determine gamut mapping for the colors of the image. Clipping-type GMAs generally map colors which are outside of the destination gamut to a color point on the destination gamut boundary. Colors which are already contained in the destination gamut are not affected. Often, clipping-type GMAs preserve the colorfulness (i.e., chroma) of an image. However, the use of a clipping-type GMA may cause some image detail in the colorful areas to be lost.

Generally, movement of color points during gamut mapping is undesirable because movement alters color appearance. Therefore, it is ordinarily desirable to minimize the movement of color points during gamut mapping.

SUMMARY

One problem with compression-type GMAs is that when an image gamut does not fill the source device gamut, the compression factor may be greater than necessary to map colors in a source image onto the gamut of the destination device. In this case, the compression-type GMA may not provide optimum preservation of color accuracy.

One problem with image-based GMAs is that when one image color is more saturated than another, the amount of compression may vary dramatically for different color points. For example, if an image contains a lot of saturated red, but has very little saturated green, the red may be compressed much more than the green. This difference in compression often results in an unnatural appearance.

The foregoing is addressed by using a boundary of a source image to affect gamut mapping. The gamut boundary of the source image is the color gamut boundary that fully encompasses all of the colors contained in the image.

Thus, in an example embodiment described herein, color management is architected so as to convert a source-side color in a source device dependent color space into a counterpart destination-side color in a destination device dependent color space. A device independent source device gamut boundary for a source device and a device independent destination device gamut boundary for a destination device are obtained. A source color image is generated in the source device dependent color space. The source color image is transformed into a device independent image in a device independent color space. An image gamut boundary for the device independent image is generated, based on the content of the device independent image. The source device gamut boundary is modified by shrinking the source device gamut boundary in a hue symmetric manner, such that hues of colors do not change, until it touches the image gamut boundary. The colors of the device independent image are mapped onto a gamut of the destination device by invoking a compression-type gamut mapping algorithm that uses the modified source device gamut boundary and the destination device gamut boundary to perform gamut mapping. The gamut mapped colors are converted into destination-side colors in the destination device dependent color space.

By virtue of shrinking the source device gamut boundary towards the image gamut boundary, the amount of compression may be reduced, thereby improving color accuracy. By virtue of shrinking the source device gamut boundary in a hue symmetric manner, the amount of compression for each color may not vary, and a more natural appearance may result. By virtue of applying the modified source device gamut boundary to a compression-type GMA, existing compression-type GMAs may be used.

In example embodiments, the source device gamut boundary can be shrunk according to the intent of the compression-type GMA. A compression point can be determined based on the intent of the compression-type GMA, and the source

device gamut boundary can be modified by moving each point on the source device gamut boundary toward the compression point until a point on the modified source device gamut boundary touches the image gamut boundary.

In response to a determination that the compression-type GMA performs lightness scaling, a lightness of the source device gamut boundary can be scaled so that maximum and minimum values of the lightness of the source device gamut boundary match maximum and minimum values of a lightness of the destination device gamut boundary. The lightness-scaled source device gamut boundary can be shrunk during modification such that only chroma components of the source device gamut boundary are modified. The modified source device gamut boundary can be re-scaled to an original lightness and used by the compression-type GMA. The lightness-scaled source device gamut boundary can be in a color space having at least a coordinate representing lightness and a coordinate representing chroma, and the lightness-scaled source device gamut boundary can be modified by moving a chroma component of each point on the lightness-scaled source device gamut boundary toward an axis representing the lightness coordinate, until a point on the modified source device gamut boundary touches the image gamut boundary.

An additional shrinking step can be performed to further shrink the source device gamut boundary past the image gamut boundary until a predetermined condition is satisfied. The predetermined condition can be based on a percentage of the device independent image color points that lie outside of the modified source device gamut boundary. The predetermined condition can be based on a threshold number of the device independent image color points that lie outside of the modified source device gamut boundary. The predetermined condition can be based on a maximum distance between a color point of the device independent image that lies outside of the modified source device gamut boundary, and the modified source device gamut boundary. The predetermined condition can be satisfied when the modified source device gamut boundary touches the destination device gamut boundary. The predetermined condition can be selected by a user. The predetermined condition can be selected using a graphical user interface that provides a preview of a resulting image.

After performing the additional shrinking step, one or more color points of the device independent image may lie outside of the modified source device gamut boundary. The outlying color points of the device independent image that lie outside the modified source device gamut boundary may lie outside the destination device gamut boundary after the compression-type GMA performs gamut mapping. Post-processing can be performed to convert the outlying color points into color points that lie within the destination device gamut boundary. The post-process can include clipping the outlying color points that lie outside of the destination device gamut boundary to a nearest color point on the destination device gamut boundary. In the alternative, a compression method can be performed during post-processing.

This brief summary has been provided so that the nature of this disclosure may be understood quickly. A more complete understanding can be obtained by reference to the following detailed description and to the attached drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a view for explaining a typical software architecture for gamut mapping using a compression-type GMA.

FIG. **2** is a representative view of computing equipment relevant to one example embodiment.

FIG. **3** is a detailed block diagram depicting the internal architecture of the host computer shown in FIG. **2**.

FIG. **4** is a representational view of color transform processing performed by a color management module according to an example embodiment.

FIG. **5** is a view for explaining software architecture of a color management module according to an example embodiment.

FIG. **6** is a view for explaining the software architecture of a gamut mapping module using a compression-type GMA and a modified source device gamut boundary according to an example embodiment.

FIG. **7** is a flow diagram for explaining color processing in a color management module according to an example embodiment.

FIG. **8** is a flow diagram for explaining modifying a source device gamut boundary according to an example embodiment.

FIG. **9** is a conceptual illustration of the CIECAM02 JCh color space.

FIG. **10** depicts example source and destination device gamut boundaries.

FIG. **11** is a view for explaining modification of an example source device gamut boundary and gamut mapping by a compression-type GMA according to an example embodiment.

FIG. **12** is a view for explaining gamut mapping by a compression-type GMA.

FIG. **13** is a flow diagram for explaining color processing in a color management module using a lightness-scaling compression-type GMA according to an example embodiment.

FIG. **14** is a view for explaining lightness-scaling of a source device gamut boundary according to an example embodiment.

FIG. **15** is a view for explaining modification of a lightness-scaled source device gamut boundary after lightness-scaling according to an example embodiment.

FIG. **16** is a view for explaining gamut mapping by a lightness-scaling compression-type GMA.

FIG. **17** is a flow diagram for explaining color processing in a color management module according to an example embodiment.

FIG. **18** is a flow diagram for explaining modification of a source device gamut boundary according to an example embodiment.

FIG. **19** is a view for explaining modification of a source device gamut boundary according to an example embodiment.

DETAILED DESCRIPTION

First Embodiment

FIG. **2** is a representative view of computing equipment, peripherals and digital devices, relevant to a first example embodiment. Computing equipment **40** includes host computer **41** which generally comprises a programmable general purpose personal computer (hereinafter "PC") having an operating system such as Microsoft® Windows® or Apple® Mac OS® or LINUX, and which is programmed as described below so as to perform particular functions and in effect to become a special purpose computer when performing these functions. Computing equipment **40** includes color monitor **43** including display screen **42**, keyboard **46** for entering text data and user commands, and pointing device **47**. Pointing device **47** preferably comprises a mouse for pointing and for manipulating objects displayed on display screen **42**.

Host computer **41** also includes computer-readable memory media such as computer hard disk **45** and DVD disk

drive **44**, which are constructed to store computer-readable information such as computer-executable process steps. DVD disk drive **44** provides a means whereby host computer **41** can access information, such as image data, computer-executable process steps, application programs, etc. stored on removable memory media. In an alternative, information can also be retrieved through other computer-readable media such as a USB storage device connected to a USB port (not shown), or through network interface **80**. Other devices for accessing information stored on removable or remote media may also be provided.

Projector **50** is a first example of a color output device, and in this example is an RGB or RGBW projector, such as a DLP™ digital projector or other display device that projects images in accordance with image data from host computer **41** onto a projection screen (not shown).

Printer **90** is a second example of a color output device, and in this example is a color laser printer which forms color images on a recording medium such as paper or transparencies or the like. Printer **90** forms color images using cyan, magenta, yellow and black colorants, although printers and other devices can be used which form color images using other colorant combinations that might or might not include black, such as a CMYKOG device.

Digital color scanner **70** is a first example of a color input device, and is provided for scanning documents and images and sending the corresponding image data to host computer **41**.

Digital color camera **60** is a second example of a color input device, and is provided for sending digital image data to host computer **41**.

Of course, host computer **41** may acquire digital image data from other sources such as a digital video camera, a local area network or the Internet via network interface **80**. Likewise, host computer **41** may interface with other color output devices, such as color output devices accessible over network interface **80**.

FIG. **3** is a detailed block diagram showing the internal architecture of host computer **41** of computing equipment **40**. As shown in FIG. **3**, host computer **41** includes central processing unit (CPU) **113** which interfaces with computer bus **114**. Also interfacing with computer bus **114** are hard disk **45**, network interface **112**, random access memory (RAM) **116** for use as a main run-time transient memory, read only memory (ROM) **117**, DVD disk interface **119**, display interface **120** for monitor **43**, keyboard interface **122** for keyboard **46**, mouse interface **123** for pointing device **47**, scanner interface **124** for scanner **70**, printer interface **125** for printer **90**, digital camera interface **126** for digital camera **60**, and digital projector interface **127** for digital projector **50**.

RAM **116** interfaces with computer bus **114** so as to provide information stored in RAM **116** to CPU **113** during execution of the instructions in software programs such as an operating system, application programs, color management modules, and device drivers. More specifically, CPU **113** first loads computer-executable process steps from fixed disk **45**, or another storage device into a region of RAM **116**. CPU **113** can then execute the stored process steps from RAM **116** in order to execute the loaded computer-executable process steps. Data such as color images or other information can be stored in RAM **116**, so that the data can be accessed by CPU **113** during the execution of computer-executable software programs, to the extent that such software programs have a need to access and/or modify the data.

As also shown in FIG. **3**, hard disk **45** contains computer-executable process steps for operating system **130**, and application programs **131**, such as word processing programs or a graphical image management programs. Hard disk **45** also contains computer-executable process steps for device drivers for software interface to devices, such as input device drivers **132**, output device drivers **133**, and other device drivers **134**. Image files **138**, including color image files, and other files **139** are available for output to color output devices and for manipulation by application programs.

Color management module (CMM) **135** comprises computer-executable process steps executed by a computer for managing colors so as to maintain good color fidelity for color images that are transferred from a source device to a destination device, such as the transfer of color image data from capture by digital camera **60** to display by projector **50**. CMM **135** generally comprises computer-executable process steps that accept a source color image having colors with colorant values in a source device dependent color space, and that generate a destination color image having colors with counterpart colorant values in a destination device dependent color space. More specifically, CMM **135** obtains a device independent source device gamut boundary for a source device and a device independent destination device gamut boundary for a destination device. CMM **135** obtains a source color image in the source device dependent color space and transforms the source color image into a device independent image in a device independent color space. CMM **135** generates an image gamut boundary for the device independent image based on the color content of the device independent image. CMM **135** modifies the source device gamut boundary by shrinking the source device gamut boundary in a hue symmetric manner, such that hues of colors do not change, until it touches the image gamut boundary, and maps colors of the device independent image onto a gamut of the destination device by invoking a compression-type gamut mapping algorithm that uses the modified source device gamut boundary and the destination device gamut boundary to perform gamut mapping, wherein the gamut mapped colors are converted into destination-side colors in the destination device dependent color space.

The computer-executable process steps for CMM **135** may be configured as a part of operating system **130**, as part of a device driver such as a printer driver, or as a stand-alone application program such as a color management system. They may also be configured as a plug-in or dynamic link library (DLL) to the operating system, device driver or application program. For example, CMM **135** according to example embodiments may be incorporated in a device driver for execution in a computing device, such as a printer driver, embedded in the firmware of a device, such as a printer, or provided in a stand-alone color management application for use on a general purpose computer. In one example embodiment described herein, CMM **135** is incorporated directly into the operating system for general purpose host computer **41**. It can be appreciated that the present disclosure is not limited to these embodiments and that the disclosed color management module may be used in other environments in which color management is used.

FIG. **4** shows a representational view of color transform processing performed by a color management system. As explained hereinabove, a source color image **140** for a source device contains colorant values in a source device dependent color space, such as RGB colorant values in an RGB color space for a scanner or camera or LCD display. CMM **135** is applied to the source device colorant values so as to obtain a counterpart color image **145** for a destination device. Because of the effect of processing by CMM **135**, the destination color image **145** exhibits good color fidelity relative to the source color image **140**, despite a change from the source device to

the destination device, and despite other changes such as changes in viewing conditions and output media. Color image **145** contains colorant values in the destination device dependent color space, such as CMYK colorant values in a CMYK color space for a color laser printer.

In use of CMM **135**, nearly any device can serve as the source device, and nearly any device can serve as the destination. In one example, the source device might be digital camera **60** which captures an image of a natural scene, and the destination device might be color laser printer **90** which produces a printout of the captured image. In other examples, the source device might be color laser printer **90** printer which has produced a printout of a color image, and the destination device might be scanner **70** which scans the printout. In another example, the source device might be display **43** which is displaying a color image, and the destination device might be projector **50** for which it is desired to project a counterpart color image with good fidelity to the image being displayed by the display **43**. In further examples of use of CMM **135**, projector **50** can operate either as a source device or as a destination device. One example of projector **50** operating as a source device is in a situation where it is desired to print an image on printer **90** in correspondence to an image being projected by projector **50**. One example of projector **50** operating as a destination device is a situation where it is desired to project an image corresponding to an image captured by digital camera **60**. Other examples are situations where it is desired to project an image in correspondence to an image scanned by scanner **70**, or displayed by display **43** on screen **42**. Other combinations and permutations are possible and will be evident to those of ordinary skill in the art.

FIG. **5** is a view for explaining software architecture of CMM **135** according to the first example embodiment. As seen in FIG. **5**, CMM **135** is architected in multiple layers, with a module in each layer communicating with modules in each of two adjacent layers. The layers correspond generally to different color spaces, and also to colors that have been gamut-mapped or that have not yet been gamut-mapped. Thus, there are layers for a source device dependent color space **161** (such as an sRGB color space) and a destination device dependent color space **162** (such as a CMYK color space), layers for device independent color spaces **163** (such as CIEXYZ color space, although the device independent color space on the source device side is not necessarily the same as the device independent color space on the destination device side), and layers for device independent color appearance spaces **164** (such as CIECAM02 JCh color space, but which likewise are not necessarily the same color spaces on the source side and the destination device side). This latter layer for device independent color appearance spaces **164** includes colors which have not yet been gamut-mapped and those which have.

A detailed description of the modules in the various layers will now be provided.

A source device module **166** transforms colors in source device dependent color space **161** into counterpart colors in the device independent color space **163**, by using a source device model. The source device model implemented by source device module **166** is one of multiple selectable models, with the selection being made from a collection **167** of source device models. The collection includes pre-defined baseline models which might include, for example, a CRT device model, an LCD device model, an RGB capture device model, an RGB projector device model, an RGB printer device model, a CMYK printer device model, an RGB virtual device model (which can be used for wcsRGB color space), or an ICC (International Color Consortium) virtual device model (which enables use of ICC profiles in measurement-based transforms used herein). In addition, the selection of the source device model that is used by source device module **166** is extensible via a device model plug-in, so as to permit use of a device model for a device that does not conform closely enough to one of the pre-defined device models.

Source device module **166** implements parameters of the selected device model by using a source device profile which characterizes parameters for the particular device under consideration. As one example of the difference between a device model and a device profile, the device model might accurately model an entire family of devices, such as LCD displays, in terms of parameters such as white point and black point. The device profile provides values for these parameters, individualized for one particular device within the family. In this embodiment, the device profiles (both source device and destination device) are provided in the form of measurements of color performance for the target device.

The source device profile is normally provided to the source device module **166** from a collection **167** of pre-defined source device profiles, corresponding to devices that are installed on host computer **41**.

Source colors in device independent color space **163** are mapped to device independent color appearance space **164** by color appearance module **169**, which transforms colors based on a color appearance model profile (CAMP). The CAMP provides a measure of viewing conditions at the source device. The source device CAMP may be selected from a collection **171** of pre-defined CAMPs, which typify frequently encountered viewing conditions.

Source colors in device independent color appearance space **164** are then gamut mapped by a gamut mapping module **172** which implements a gamut-mapping model so as to obtain gamut-mapped colors in device independent color appearance space **164**. The purpose of the gamut-mapping module **172** is to reconcile the differences in the gamut of colors reproducible by the source device as against the gamut of colors reproducible by the destination device. These two gamuts are almost always different, and thus colors in source device dependent color space **161** almost always require adjustment when calculating counterpart colors in destination device dependent color space **162**.

Gamut mapping module **172** typically implements a GMA selected from a collection **173** of GMAs. For example, the collection might include one or more of the following compression-type GMAs: (a) a midpoint compression GMA; (b) a cusp point compression GMA; (c) a knee point compression GMA; and (d) a sigmoidal Gaussian knee clipping algorithm (SGKC), which is largely equivalent to ICC's preferred, pictorial, or perceptual intent. In addition, the selection for the gamut mapping module **172** is typically extensible via a plug-in framework, so as to permit use of a gamut mapping model that does not conform closely enough to one of the pre-defined GMAs.

A gamut mapping profile is provided to gamut mapping module **172**, wherein the profile provides values for parameters in the GMA, and wherein the profile is selectable from among a collection **174** of pre-defined gamut mapping profiles. A gamut mapping profile can include information regarding lightness-scaling and the intent of the GMA.

Gamut-mapped colors in device independent color appearance space **164** are mapped to counterpart colors in device independent color space **163** by color appearance module **177**, which transforms colors based on a color appearance model profile (CAMP). The CAMP provides a measure of viewing conditions at the destination device. The destination

device CAMP may be selected from a collection **178** of pre-defined CAMPs, which typify frequently encountered viewing conditions.

Colors in device independent color space **163** are transformed into counterpart colors in the destination device dependent color space **162** by destination device module **179**, which transforms colors in the device independent color space **163** into counterpart colors in the destination device dependent color space **162** by using a destination device model. Like the source device model, the destination device model implemented by destination device module **179** is one of multiple selectable models, with the selection being made from a collection **181** of destination device models. The collection might be the same collection as source device collection **167**, and includes pre-defined baseline models such as a CRT device model, an LCD device model, an RGB capture device model, an RGB projector device model, an RGB printer device model, a CMYK printer device model, an RGB virtual device model (which can be used for wcsRGB color space), or an ICC virtual device model (which enables use of ICC profiles in measurement-based transforms used herein). In addition, the selection for the destination device model that is used by destination device module **179** is extensible via a device model plug-in, so as to permit use of a device model for a device that does not conform closely enough to one of the pre-defined device models.

Similar to the source side, destination device module **179** implements parameters of the selected device model by using a destination device profile which characterizes parameters for the particular device under consideration. As before, in this example embodiment, the destination device profile is provided in the form of measurements of color performance for the target device. The destination device profile is normally provided to the destination device module **179** from a collection **182** of pre-defined destination device profiles, corresponding to devices that are installed on host computer device **41**.

FIG. **6** is a view for explaining the software architecture of gamut mapping module **172** in more detail. As shown in FIG. **6**, source device gamut boundary module **100** creates source device gamut boundary **103** for a source device using source device module **166** and color appearance module **169**. A source device gamut represents a sampling of all possible colors that can be reproduced by the source device. Source device gamut boundary module **100** uses source device module **166** to generate values of the source device gamut in device independent color space **163**. Source device gamut values in device independent color space **163** are then converted into device independent color appearance space **164** (e.g., in the CIECAM02 JCh color appearance space) by color appearance module **169**, which uses source device viewing conditions obtained from a CAMP to perform conversion. Source device gamut boundary module **100** then uses the device independent appearance values produced by color appearance module **169** to generate source device gamut boundary **103**.

Likewise, destination device gamut boundary module **102** creates destination device gamut boundary **107** for a destination device using destination device module **179** and color appearance module **177**. A destination device gamut represents a sampling of all possible colors that can be reproduced by the destination device. Destination device gamut boundary module **102** uses destination device module **179** to generate values of the destination device gamut in device independent color space **163**. Destination device gamut values in device independent color space **163** are then converted into device independent color appearance space **164** (e.g., in the CIECAM02 JCh color appearance space) by color appearance module **177**, which uses destination device viewing conditions obtained from a CAMP to perform conversion. Destination device gamut boundary module **102** then uses the device independent appearance values produced by color appearance module **177** to generate destination device gamut boundary **107**.

Image gamut boundary module **101** creates image gamut boundary **104** for device independent source image colors **108** which are in device independent color appearance space **164**. An image gamut represents all source image colors **108** contained in an image. Source image colors **108** are colors of an image received from color appearance module **169**. Image gamut boundary module **101** uses device independent source colors **108** to generate image gamut boundary **104**.

Modification module **105** operates as a pre-process to compression-type GMA **109**. In particular, before compression-type GMA **109** is invoked, modification module **105** modifies source device gamut boundary **103** by shrinking source device gamut boundary **103** to create modified source device gamut boundary **106**. Modification module **105** shrinks source device gamut boundary **103** using the image gamut boundary **104** as a reference. Specifically, modification module **105** shrinks source device gamut boundary **103** until any part of the modified source device gamut boundary touches image gamut boundary **104**. Compression-type GMA **109** then uses modified source device gamut boundary **106** and destination device gamut boundary **107** to convert device independent source image colors **108** to destination device gamut colors **110** in the device independent color appearance space **164**. Destination device gamut colors **110** are device independent colors within the gamut of the destination device.

Although the architecture shown in FIG. **6** has been described herein as a part of gamut mapping module **172**, it should be appreciated that the process can also be performed in other modules.

FIG. **7** is a flow diagram for explaining color processing in a color management module using a modified source device gamut boundary according to the first example embodiment. The process steps shown in FIG. **7** are computer-executable process steps stored on a computer-readable memory medium such as at **135** on disk **45**, and are executed by CPU **113** of host computer **41**, so as to implement a color management module in which a source-side color in a source device dependent color space is converted into a counterpart destination-side color in a destination device dependent color space. Briefly, according to the process steps shown in FIG. **7**, a device independent source device gamut boundary for a source device and a device independent destination device gamut boundary for a destination device are obtained. A source color image in a source device dependent color space is obtained, and the source color image is transformed into a device independent image in a device independent color space. An image gamut boundary for the device independent image is generated based on the color content of the device independent image. The source device gamut boundary is modified by shrinking the source device gamut boundary in a hue symmetric manner, such that hues of colors do not change, until it touches the image gamut boundary. Colors of the device independent image are mapped onto a gamut of the destination device by invoking the compression-type GMA that uses the modified source device gamut boundary and the destination device gamut boundary to perform gamut mapping, and the gamut mapped colors are converted into destination-side colors in the destination device dependent color space.

In more detail, in step S**701**, modification module **105** obtains the source device gamut boundary for the source device and obtains the destination device gamut boundary for the destination device. As described above in reference to FIG. **6**, the source device gamut boundary and the destination device gamut boundary are represented in device independent color appearance space **164**. In addition, in step S**701**, the source color image consisting of source image colors **108** in device independent color appearance space **164** is obtained.

In step S**702**, an image gamut boundary is generated based on the color content of device independent source image colors **108** which are received from color appearance module **169**. As described above, source image colors **108** are in device independent color appearance space **164**. Image gamut boundary module **101** uses device independent source image colors **108** to generate the image gamut boundary in device independent color appearance space **164**.

In step S**703**, the device independent source device gamut boundary **103** is modified by modification module **105** to generate the modified source device gamut boundary **106**. In particular, modification module **105** modifies source device gamut boundary **103** by shrinking source device gamut boundary **103** in a hue symmetric manner, such that hues of colors do not change, until any point on the modified source device gamut boundary touches any point on image gamut boundary **104**. Modification of the source device gamut boundary in a hue symmetric manner is discussed in more detail below with respect to FIG. **8**.

In step S**704**, device independent source image colors **108** are mapped to destination device gamut colors **110** in device independent color appearance space **164** by compression-type GMA **109**. More specifically, colors of the device independent source image **108** are mapped onto a gamut of the destination device by invoking compression-type GMA **109** which uses modified source device gamut boundary **106** and destination device gamut boundary **107** to perform gamut mapping. The gamut mapping process of compression-type GMA **109** will be discussed in more detail below with respect to FIG. **11**.

In step S**705**, gamut mapped colors **110** are converted into destination-side colors in destination device dependent color space **162** by CMM **135**. In particular, as discussed above in reference to FIG. **5**, gamut-mapped colors in device independent color appearance space **164** are mapped to counterpart colors in device independent space **163** by color appearance module **177**, which transforms colors based on a CAMP. Colors in device independent color space **163** are transformed into counterpart colors in destination device dependent color space **162** by destination device module **179** using a destination device model.

FIG. **8** is a flow diagram for explaining the modification step S**703** of FIG. **7** in more detail. The process steps shown in FIG. **8** are computer-executable process steps stored on a computer-readable memory medium such as at **135** on disk **45**, and are executed by CPU **113** of host computer **41**, so as to modify source device gamut boundary **103**. Briefly, according to the process steps shown in FIG. **8**, an intent of compression-type GMA **109** is obtained, a compression point is determined based on the obtained intent of compression-type GMA **109**, and the source device gamut boundary is modified by moving each point on the source device gamut boundary toward the compression point, until a point on the modified source device gamut boundary touches the image gamut boundary.

In more detail, in step S**801**, modification module **105** obtains the intent of compression-type GMA **109** from the corresponding GMA profile **174**. Compression-type GMA **109** can perform color conversion according to various color reproduction intents which are specified in GMA profiles **174**. Color reproduction intents define a desired relationship between the source and destination color values. The intent of the GMA dictates the direction and magnitude of compression. For example, the compression direction can be toward the halfway point on the lightness axis, or toward the lightness axis keeping lightness constant. Compression can also change with respect to the location of the color point to be compressed in the gamut. Additionally, GMA compression can be linear or non-linear. Modification module **105** shrinks the source device gamut boundary closely following the intent of compression-type GMA **109**. In other words, modification module **105** accounts for the compression direction and the magnitude of GMA **109**. For example, if the compression direction of GMA **109** is toward the halfway point on the lightness axis, then the source device gamut boundary is shrunk in that direction.

In step S**802**, modification module **105** determines a compression point based on the intent obtained in step S**801**. The compression point is a point toward which the color point to be compressed will be moved. In step S**803**, modification module **105** modifies the source device gamut boundary **103** by moving each point on source device gamut boundary **103** toward the compression point, until a point on the modified source device gamut boundary touches image gamut boundary **104**. These steps are explained in more detail with reference to FIG. **11**, below.

FIG. **9** is a conceptual illustration of the CIECAM02 JCh color appearance space. Color appearance space **164** is a device independent color space which accounts for viewing conditions providing by a CAMP. JCh color appearance space is an example of a device independent color appearance space **164** commonly used for gamut mapping.

JCh color space is a cylindrical space where the C axis represents chroma, the J axis represents lightness, and the angle h represents hue. Angle h is the angle from the J axis around the cylinder.

Compression-type GMA **109** operating in JCh color space normally compresses toward the J axis. For example, the compression direction can be toward the J axis keeping the J value constant, toward the midpoint of the J axis, toward the J value of a cusp point at a particular hue, or a combination of these, depending on the location of the color point to be compressed. Since compression-type GMA **109** typically performs compression in the direction of the J axis, the line of compression typically contains a constant hue. Therefore, gamut mapping can be illustrated by looking at cross-sections of the gamuts.

The example embodiments described herein are illustrated in JCh color appearance space. However, it should be appreciated that the techniques are applicable in any color space.

FIG. **10** is a view illustrating source and destination device gamut boundaries in the JCh color space. As noted above, compression-type GMA **109** typically performs compression keeping angle h constant. Therefore, for the purposes of explaining gamut mapping by compression-type GMA **109**, only the J axis and the C axis of the JCh color space are illustrated in FIG. **10**.

Source device gamut boundary **151** is created by source device gamut boundary module **100**. Source device gamut boundary **151** is the outermost perimeter of the source device gamut containing the entire range of colors capable of being reproduced by a source device. Likewise, destination device gamut boundary **150** is created by destination device gamut boundary module **102**. Destination device gamut boundary **150** is the outermost perimeter of the destination device

gamut containing the entire range of colors capable of reproduction by a destination device.

FIG. **11** is a view for explaining modification of a source device gamut boundary and gamut mapping according to the first example embodiment. As discussed above, source device gamut boundary **151** and destination device gamut boundary **150** are created. Referring to the process steps of FIG. **7**, in step S**701**, modification module **105** obtains source device gamut boundary **151** and destination device gamut boundary **150**. A device independent source color image containing device independent source image colors **108** is also obtained in step S**701**. In step S**702**, image gamut boundary module **101** generates image gamut boundary **155**. Image gamut boundary **155** is the outermost perimeter of the image gamut encompassing all of the colors contained in an image.

In step S**703**, modification module **105** modifies source device gamut boundary **151** to generate modified source device gamut boundary **154** by shrinking source device gamut boundary **151** in a hue symmetric manner, such that hues of colors do not change, until the modified source device gamut boundary touches image gamut boundary **155**, as described above with respect to FIG. **8**. Shrinking in a hue symmetric manner assumes that color hue remains constant and typically reduces the difference in compression that often occurs when one image color is more saturated than another such that image colors are preserved.

More specifically, modification module **105** obtains an intent of compression-type GMA **109** and shrinks source device gamut boundary **151** according to the intent. The intent of GMA **109** dictates the direction and magnitude of compression performed by GMA **109**. Compression point **156** is determined based on the obtained intent of compression-type GMA **109**. In the example illustrated by FIG. **11**, compression point **156** is determined to be the point J=50 on the J axis. Modification module **105** produces modified source gamut boundary **154** by shrinking each point on source device gamut boundary **151** towards compression point **156**, until a point on the source device gamut boundary touches image gamut boundary **155**. Thus, source device gamut boundary **151** is shrunk symmetrically using the same compression direction as compression-type GMA **109** and preserving the relative shape of source device gamut boundary **151**.

In step **704**, compression-type GMA **109** performs gamut mapping using modified source gamut boundary **154** and destination device gamut boundary **150** to map the device independent source image colors to the destination device gamut.

In order to illustrate the compression process, a compression line can be envisioned from compression point **156** through a color point to be compressed, for example, color points C and H. It can then be determined where the compression line intersects modified source device gamut boundary **154** and destination device gamut boundary **150**. As shown in FIG. **11**, if color point C is to be compressed, the compression line from compression point **156** to color point C intersects modified source device gamut boundary **154** at point C and destination device gamut boundary **150** at point B. If color point H is to be compressed, the compression line from compression point **156** to color point H intersects modified source device gamut boundary **154** at point F and destination device gamut boundary **150** at point G. In this example, if compression-type GMA **109** uses global compression, then the new distance from the compression point to the color point to be compressed is determined by Equation 1:

$$D_{CP}=D_P*(D_D/D_S) \quad \text{(Equation 1)}$$

The color point to be compressed is moved along the compression line to this new distance, D_{CP}, from the compression point. In the above equation, D_P represents the distance from the compression point to the color point to be compressed. D_D represents the distance from the compression point to the point where the compression line intersects the destination device gamut boundary. D_S represents the distance from the compression point to the point where the compression line intersects the source device gamut boundary.

For example, if the color point to be compressed is color point C, D_P is equal to the distance from point C to compression point **156**, D_D is equal to the distance from point B to compression point **156**, and D_S is equal to the distance from point C to compression point **156**. Using these values, the new distance of color point C from compression point **156** is calculated and color point C is moved to point B.

Similarly, if the color point to be compressed is color point H, D_P is equal to the distance from point H to compression point **156**, D_D is equal to the distance from point G to compression point **156**, and D_S is equal to the distance from point F to compression point **156**. Using these values, the new distance of color point H from compression point **156** is calculated and color point H is moved to point K.

FIG. **12** is a view for explaining gamut mapping by a compression-type GMA according to the first example embodiment in a case where the image gamut boundary already touches source device gamut boundary **151** before modification. In the case where the image gamut boundary already touches source device gamut boundary **151**, source device gamut boundary **151** cannot be further shrunk without leaving some source image color points outside of source device gamut boundary **151**. If source device gamut boundary **151** is not shrunk, or is shrunk only a little, compression-type GMA **109** would typically yield similar results to that of a standard compression-type GMA using an unmodified source device gamut boundary and a destination device gamut boundary.

For example, if source device gamut boundary **151** is not modified, then compression-type GMA **109** uses source device gamut boundary **151** and destination device gamut boundary **150** to gamut map source image colors to the destination device gamut. Thus, using equation (1) from above, if the color point to be compressed is color point C, D_P is equal to the distance from point C to compression point **156**, D_D is equal to the distance from point B to compression point **156**, and D_S is equal to the distance from point D to compression point **156**. Using these values, the new distance of color point C from compression point **156** is calculated and color point C is moved to point A. In contrast, as shown in FIG. **11**, if compression-type GMA **109** uses modified source device gamut boundary **154** to affect gamut mapping, color point C is compressed to point B rather than point A. Therefore, the mapping performed in FIG. **11** using modified source device gamut boundary **154** results in less movement of color point C, which improves preservation of color saturation and which increases accuracy in color reproduction.

Similarly, if the color point to be compressed is color point H, D_P is equal to the distance from point H to compression point **156**, D_D is equal to the distance from point G to compression point **156**, and D_S is equal to the distance from point E to compression point **156**. Using these values, the new distance of color point H from compression point **156** is calculated and color point H is moved to point L. In contrast, as shown in FIG. **11**, if compression-type GMA **109** uses modified source device gamut boundary **154** to affect gamut mapping, color point H is compressed to point K rather than point L. Therefore, the mapping performed in FIG. **11** using

modified source device gamut boundary **154** results in less movement of color point H, which improves preservation of color saturation and which increases accuracy in color reproduction.

Thus, in many cases, shrinking of the source device gamut boundary typically reduces the overall compression of colors during gamut mapping. Additionally, because the source device gamut boundary is shrunk symmetrically, modifying the source device gamut boundary typically does no harm to the difference in compression between various color points during gamut mapping. Furthermore, in the case that the source device gamut boundary is not modified, or is modified by only a small amount, the compression-type GMA typically yields similar results to that of a standard compression-type GMA which uses an unmodified source device gamut boundary. Thus, the compression-type GMA typically does no harm to the amount of overall color compression in comparison to a standard GMA using an unmodified source device gamut boundary.

Second Embodiment

FIG. **13** is a flow diagram for explaining color processing in a color management module using a lightness-scaling compression-type GMA according to a second example embodiment. The process steps shown in FIG. **13** are computer-executable process steps stored on a computer-readable memory medium, and executed by a CPU of a host computer similar to the host computer **41** described above with respect to FIG. **3**, so as to implement a color management module similar to CMM **135**, described above with respect to FIG. **5**, in which a source-side color in a source device dependent color space is converted into a counterpart destination-side color in a destination device dependent color space.

The color management module includes a source device module similar to source device module **166** of FIG. **5**, color appearance modules similar to color appearance module **169** and color appearance module **177** of FIG. **5**, and a destination device module similar to destination device module **179** of FIG. **5**. The color management module also includes a gamut mapping module. In the second embodiment, the gamut mapping module implements a compression-type GMA which performs lightness-scaling before compression. The gamut mapping module reconciles the differences in the gamut of colors reproducible by the source device as against the gamut of colors reproducible by the destination device. The gamut mapping module includes a source device gamut boundary module similar to source device gamut boundary module **100** of FIG. **6**, an image gamut boundary module similar to image gamut boundary module **101** of FIG. **6**, a destination device gamut boundary module similar to destination device gamut boundary module **102** of FIG. **6**. The gamut mapping module also includes a modification module. In the second embodiment, the modification module modifies the source device gamut boundary, taking into account the lightness-scaling performed by the compression-type GMA.

According to the process steps shown in FIG. **13**, a device independent source device gamut boundary for a source device and a device independent destination device gamut boundary for a destination device are obtained. A source color image in a source device dependent color space is obtained. The source color image is transformed into a device independent image in a device independent color space and an image gamut boundary for the device independent image is generated based on the color content of the device independent image. Responsive to a determination that the compression-type GMA does not perform lightness scaling, the source device gamut boundary is modified by shrinking the source device gamut boundary in a hue symmetric manner, such that hues of colors do not change, until it touches the image gamut boundary. Colors of the device independent image are mapped onto a gamut of the destination device by invoking the compression-type GMA that uses the modified source device gamut boundary and the destination device gamut boundary to perform gamut mapping, and the gamut mapped colors are converted into destination-side colors in the destination device dependent color space. On the other hand, responsive to a determination that the compression-type GMA performs lightness scaling, a lightness of the source device gamut boundary is scaled so that maximum and minimum values of the lightness of the source device gamut boundary match maximum and minimum values of a lightness of the destination device gamut boundary. The lightness-scaled source device gamut boundary is shrunk such that only chroma components of the source device gamut boundary are modified, the modified lightness-scaled source device gamut boundary is re-scaled to an original lightness, and the re-scaled and modified source device gamut boundary is used by the lightness-scaling compression-type GMA.

In more detail, in step **S1301**, the source device gamut boundary for a source device is obtained, and the destination device gamut boundary for a destination device is obtained, through processes similar to those described above in reference to FIG. **6**. The source device gamut boundary and the destination device gamut boundary are in a device independent color appearance space (e.g., CIECAM02 JCh color space). In addition, in step **S1301**, a source color image consisting of device independent source image colors in the device independent color appearance space is obtained from a color appearance module, similar to color appearance module **169** of FIG. **5**.

In step **S1302**, an image gamut boundary is generated based on the color content of the device independent source image colors, through processes similar to those described above in reference to FIG. **6**.

In step **S1306** is it determined whether the compression-type GMA performs lightness scaling. A gamut mapping profile includes information regarding lightness-scaling, and the determination is made by analyzing the gamut mapping profile associated with the compression-type GMA. Many compression-type GMAs that use source and destination device gamut boundaries perform lightness scaling on the source device gamut boundary to match the lightness range of the destination device gamut boundary before compressing image colors. Compression-type GMAs can also perform lightness scaling on the source color image color points to match a lightness of the source device gamut boundary.

If it is determined in step **S1306** that the compression-type GMA performs lightness scaling ("YES" at step **S1306**), processing proceeds to step **S1307**. In step **S1307**, a lightness of the source device gamut boundary is pre-compressed to match the range of the destination device gamut boundary. In particular, the lightness of source device gamut boundary is scaled so that maximum and minimum values of the lightness of the source device gamut boundary match maximum and minimum values of a lightness of the destination device gamut boundary. The same lightness scaling factor is also applied to the image gamut boundary. This process is described below in more detail with respect to FIG. **14**.

In step **S1308**, the chroma components of the source device gamut boundary are modified. In particular, if the lightness-scaled source device gamut boundary is in a color space having at least a coordinate representing lightness and a coordinate representing chroma, the lightness-scaled source device gamut boundary is modified by moving a chroma component of each point on the lightness-scaled source

device gamut boundary incrementally toward an axis representing the lightness coordinate, until any point on the modified source device gamut boundary touches any point on the image gamut boundary which is not on the lightness coordinate axis. Modification of the chroma components of the lightness-scaled source device gamut boundary is performed in a hue symmetric manner, keeping lightness constant. Shrinking in a hue symmetric manner assumes that color hue remains constant and typically reduces the difference in compression that often occurs when one image color is more saturated than another, such that image colors are preserved.

In the second embodiment, the compression direction of the lightness-scaled source device gamut boundary may not exactly match the intent of the compression-type GMA, but the average compression direction for all points on the lightness-scaled source device gamut boundary may still be true to the GMA's intent and over-compression may still be minimized. The direction in which the lightness-scaled source device gamut boundary is compressed will ordinarily match the intent of the compression-type GMA if the intent of the compression-type GMA preserves lightness, i.e. performs chroma-only compression.

In step **S1309**, the modified lightness-scaled source device gamut boundary is re-scaled to the original lightness maximum and minimum of the source device gamut boundary. This re-scaling step is performed in order to prepare the modified lightness-scaled source device gamut boundary for use by the lightness scaling compression-type GMA, since this GMA will perform lightness scaling on its own. After the GMA performs lightness scaling on the re-scaled source device gamut boundary, it will use the modified lightness-scaled source device gamut boundary in order to affect gamut mapping in step **S1310**.

In step **S1310**, the device independent source image colors obtained in step **S1301** are mapped to destination device gamut colors by the compression-type GMA using the re-scaled source device gamut boundary and the destination device gamut boundary. The compression-type GMA performs lightness scaling before compression, as determined in step **S1306**. The gamut mapping process of a lightness scaling compression-type GMA is described in more detail below with respect to FIG. **16**.

In step **S1305**, the gamut mapped colors are converted to colors in a destination device dependent color space. Through a process similar to that described above in reference to FIG. **5**, gamut-mapped colors which are in a device independent color appearance space are mapped to counterpart colors in a device independent space. The colors in the device independent color space are transformed into counterpart colors in the destination device dependent color space using a destination device model of the destination device.

On the other hand, if it is determined in step **S1306** that the compression-type GMA does not perform lightness scaling ("NO" at step **S1306**), then processing proceeds to step **S1303**. In step **S1303**, the source device gamut boundary is modified to generate the modified source device gamut boundary. In particular, the source device gamut boundary is modified by shrinking the source device gamut boundary in a hue symmetric manner, such that hues of colors do not change, until any point on the modified source device gamut boundary touches any point on the image gamut boundary.

In step **S1304**, the device independent source image colors obtained in step **S1301** are mapped to destination device gamut colors in a device independent color appearance space by the compression-type GMA which, as determined in step **S1306**, does not perform lightness scaling. More specifically, the device independent source image colors are mapped onto a gamut of the destination device by invoking the compression-type GMA which uses the modified source device gamut boundary and the destination device gamut boundary to perform gamut mapping. After gamut mapping is completed in step **S1304**, the processing proceeds to step **S1305** to convert the gamut mapped colors to corresponding colors in a destination device dependent color space.

FIG. **14** is a view for explaining the lightness-scaling step **S1307** of FIG. **13** in more detail. In the second embodiment gamut mapping is performed in the JCh color appearance space. Therefore, FIG. **14** depicts colors in the JCh color space. Since lightness-scaling compression-type GMAs typically keep hue angle h constant when performing lightness scaling, for the purpose of explaining lightness scaling, only the J axis and the C axis of the JCh color space are illustrated in FIG. **14**.

Example source device gamut boundary **1400** represents the outermost perimeter of the source device gamut containing the entire range of colors capable of being reproduced by a source device. Example destination device gamut boundary **1401** represents the outermost perimeter of the destination device gamut containing the entire range of colors capable of being reproduced by a destination device. Referring to the process steps in FIG. **13**, in step **S1301**, source device gamut boundary **1400** and destination device gamut boundary **1401** are obtained. The lightness of source device gamut boundary **1400** is represented by the J axis and the chroma of source device gamut boundary **1400** is represented by the C axis.

In step **S1307** of FIG. **13**, the lightness components of source device gamut boundary **1400** are scaled along the J axis so that the maximum and minimum lightness values of source device gamut boundary **1400** match the maximum and minimum values of destination device gamut boundary **1401**. Thus, the maximum lightness value for source device gamut boundary **1400**, which is point A on the J axis, is scaled to the maximum lightness value for destination device gamut boundary **1401**, which is point B on the J axis. Similarly, the minimum lightness value for source device gamut boundary **1400**, which is point D on the J axis, is scaled to the minimum lightness value for destination device gamut boundary **1401**, which is point C on the J axis. As shown in FIG. **14**, this results in lightness-scaled source device gamut boundary **1402**. Lightness-scaled source device gamut boundary **1402** is then modified in step **S1308** of FIG. **13**.

FIG. **15** is a view for explaining modifying step **S1308** of FIG. **13** in more detail. Image gamut boundary **1500** is generated in step **S1302** of FIG. **13** and is the outermost perimeter of the image gamut encompassing all of the colors contained in an image. In step **S1308**, lightness-scaled source device gamut boundary **1402** is modified by moving the chroma components, represented by the C axis, of each point on lightness-scaled source device gamut boundary **1402** incrementally and hue symmetrically toward the J axis representing lightness, until a point on the lightness-scaled source device gamut boundary touches a point on image gamut boundary **1500** which does not lie on the J axis. This results in modified lightness-scaled source device gamut boundary **1501**, which is re-scaled to the original lightness of source device gamut boundary **1400** (in step **S1309**) and then provided to the lightness scaling compression-type GMA to perform gamut mapping (in step **S1310**).

FIG. **16** is a view for explaining gamut mapping step **S1310** of FIG. **13** performed by a compression-type GMA using the re-scaled source device gamut boundary according to the second example embodiment. When the re-scaled source device gamut boundary is passed to the lightness-scaling compression-type GMA, the GMA first scales the maximum

and minimum lightness values of the re-scaled source device gamut boundary to match the maximum and minimum lightness values of destination device gamut boundary **1401** before performing gamut mapping. This results in modified lightness-scaled source device gamut boundary **1601**. The device independent source image color points are also lightness-scaled in this manner.

The GMA then compresses each color point toward the J axis, keeping the J value constant. Thus, the performed compression is lightness and hue preserving. In order to illustrate the compression process, a compression line can be envisioned from a color point to be compressed to the J axis, keeping the J value constant. The hue value is also kept constant. To illustrate, if it is assumed that the color point to be compressed is at a point (J_0, C_0, h_0), then the corresponding compression line extends from (J_0, C_0, h_0) to the point (J_0, 0, 0) on the J axis. For example, if the color point to be compressed is color point B in FIG. **16**, then the compression line extends from point F on the J axis through color point B. The compression line intersects destination device gamut boundary **1401** at a point (J_0, C_d, h_0) and intersects modified lightness-scaled source device gamut boundary **1601** at a point (J_0, C_s, h_0). Continuing with the previous example, if the color point to be compressed is color point B, the compression line intersects destination device gamut boundary **1401** at point C and intersects modified lightness-scaled source device gamut boundary **1601** at point B. The GMA proportionally compresses a color point on the line segment extending from point (J_0, 0, 0) to point (J_0, C_s, h_0) to a color point on the line segment extending from point (J_0, 0, 0) to point (J_0, C_d, h_0), so that the mapped color point will be on or within destination device gamut boundary **1401**. Thus, if the color point to be compressed is color point B, the GMA will move point B on the line segment BF to a color point on the line segment CF. Thus, the mapped location of the color point to be compressed is (J_1, C_1, h_1), where J_1, C_1 and h_1 are defined by the following equations:

$$J_1=J_0 \quad \text{(Equation 2)}$$

$$C_1=C_0\times(C_d\div C_s) \quad \text{(Equation 3)}$$

$$h_1=h_0 \quad \text{(Equation 4)}$$

This compression will cause each color point that lies on modified lightness-scaled source device gamut boundary **1601** to map to a corresponding color point on destination device gamut boundary **1401**. Therefore, all color points that were originally contained within the source device gamut will be mapped into the destination device gamut. Thus, if the color point to be compressed is color point B, the distance from the J axis to color point B is represented by the line segment from point F to point B. The distance from the J axis to destination device gamut boundary **1401** is represented by the line segment from point F to point C. The distance from the J axis to modified lightness-scaled source device gamut boundary **1601** is represented by the line segment from point F to point B. Using these values and equations (2) through (4) above, color point B will map to point C.

Similarly, if the color point to be compressed is color point C, then the compression line extends from point F through color point C. The distance from the J axis to color point C is represented by the line segment from point F to point C. The distance from the J axis to destination device gamut boundary **1401** is represented by the line segment from point F to point C. The distance from the J axis to modified lightness-scaled source device gamut boundary **1601** is represented by the line segment from point F to point B. Using these values and equations (2) through (4) above, color point C will map to point D.

On the other hand, as also shown in FIG. **16**, if the chroma components of lightness-scaled source device gamut boundary **1402** have not been shrunk, then the compression-type GMA will calculate compression values using lightness-scaled source device gamut boundary **1402**. In this case, if the color point to be compressed is color point B, the distance from the J axis to color point B is represented by the line segment from point F to point B. The distance from the J axis to destination device gamut boundary **1401** is represented by the line segment from point F to point C. The distance from the J axis to lightness-scaled source device gamut boundary **1402** is represented by the line segment from point F to point A. Using these values and equations (2) through (4) above, color point B will map to point D rather than point C.

Similarly, if the color point to be compressed is color point C and if the chroma components of lightness-scaled source device gamut boundary **1402** have not been shrunk, then the distance from the J axis to color point C is represented by the line segment from point F to point C. The distance from the J axis to destination device gamut boundary **1401** is represented by the line segment from point F to point C. The distance from the J axis to lightness-scaled source device gamut boundary **1402** is represented by the line segment from point F to point A. Using these values and equations (2) through (4) above, color point C will map to point E rather than point D.

Therefore, as shown using the example gamut boundaries depicted in FIG. **16**, when the lightness-scaling compression-type GMA uses modified source device gamut boundary **1501**, the amount of movement of each color point during compression is minimized.

Occasionally, due to arithmetic precision error or other error, some color points will remain outside destination device gamut boundary **1401** after gamut mapping. Therefore, the GMA will typically ensure that no color points remain outside destination device gamut boundary **1401** by clipping these points directly to the nearest color point on the destination device gamut.

Third Embodiment

FIG. **17** is a flow diagram for explaining color processing in a color management module including a post-processing step according to a third example embodiment. The process steps shown in FIG. **17** are computer-executable process steps stored on a computer-readable memory medium, and executed by a CPU of a host computer similar to host computer **41** which is described above with respect to FIG. **3**, so as to implement a color management module similar to CMM **135**, which is described above with respect to FIG. **5**, in which a source-side color in a source device dependent color space is converted into a counterpart destination-side color in a destination device dependent color space.

The color management module includes a source device module similar to source device module **166** of FIG. **5**, color appearance modules similar to color appearance module **169** and color appearance module **177** of FIG. **5**, and a destination device module similar to destination device module **179** of FIG. **5**. The color management module also includes a gamut mapping module. In the third embodiment, the gamut mapping module performs a post-processing step after gamut mapping. The gamut mapping module reconciles the differences in the gamut of colors reproducible by the source device as against the gamut of colors reproducible by the destination device. The gamut mapping module includes a source device gamut boundary module similar to source device gamut

boundary module **100** of FIG. **6**, an image gamut boundary module similar to image gamut boundary module **101** of FIG. **6**, and a destination device gamut boundary module similar to destination device gamut boundary module **102** of FIG. **6**. The gamut mapping module also includes a modification module. In the third embodiment, the modification module modifies the source device gamut boundary and performs an additional modifying step to further shrink the source device gamut boundary past the image gamut boundary.

Briefly, according to the process steps shown in FIG. **17**, a device independent source device gamut boundary for a source device and a device independent destination device gamut boundary for a destination device are obtained, a source color image in a source device dependent color space is obtained, the source color image is transformed into a device independent image in a device independent color space, an image gamut boundary for the device independent image is generated based on the color content of the device independent image and the source device gamut boundary is modified by shrinking the source device gamut boundary in a hue symmetric manner, such that hues of colors do not change, until it touches the image gamut boundary. The source device gamut boundary is further shrunk past the image gamut boundary, until a predetermined condition is satisfied. Colors of the device independent image are mapped onto a gamut of the destination device by invoking a compression-type GMA that uses the modified source device gamut boundary and the destination device gamut boundary to perform gamut mapping. Post-processing is performed to convert outlying color points which lie outside of the destination device gamut boundary after gamut mapping into color points that lie within the destination device gamut boundary. The gamut mapped colors are converted into destination-side colors in a destination device dependent color space.

In more detail, in step **S1701**, the source device gamut boundary for a source device is obtained and the destination device gamut boundary for a destination device is obtained through processes similar to those described above in reference to FIG. **6**. The source device gamut boundary and the destination device gamut boundary are represented in a device independent color appearance space (e.g., CIECAM02 JCH color space). In addition, in step **S1701**, a source color image consisting of device independent source image colors in the device independent color appearance space is obtained from a color appearance module similar to color appearance module **169** of FIG. **5**.

In step **S1702**, an image gamut boundary is generated based on the color content of the device independent source image colors, which are in the color appearance space, through processes similar to those described above with respect to FIG. **6**.

In step **S1703**, the source device gamut boundary is modified to generate the modified source device gamut boundary. In particular, the source device gamut boundary is modified by shrinking the source device gamut boundary in a hue symmetric manner, such that hues of colors do not change, until any point of the modified source device gamut boundary touches any point of the image gamut boundary.

In some situations, it is advantageous to shrink the source device gamut boundary past the image gamut boundary. For example, a number of image color points at the edge of the image gamut boundary could prevent the source device gamut boundary from being shrunk more than a small amount. Also, these color points may not be crucial to the image and may occur in very small numbers. Thus, according to the third embodiment, the source device gamut boundary is additionally shrunk past the image gamut boundary leaving one or more color points of the device independent image outside of the modified source device gamut boundary. These outlying color points may lie outside of the destination device gamut boundary after the compression-type GMA performs gamut mapping. This modification step is explained in greater detail below with respect to FIG. **18**.

In step **S1704**, the device independent source image colors obtained in step **S1701** are mapped to destination device gamut colors in a device independent color appearance space by a compression-type GMA. More specifically, the device independent source image colors are mapped onto a gamut of the destination device by invoking the compression-type GMA which uses the modified source device gamut boundary and the destination device gamut boundary to perform gamut mapping.

Step **S1705** is a post-processing step for converting outlying color points into color points that lie on or within the destination device gamut boundary. Outlying color points are color points that lie outside of the destination device gamut boundary after gamut mapping by the compression-type GMA. According to the third embodiment, the post-processing step **S1705** involves clipping each outlying color point to a nearest color point on the destination device gamut boundary. According to another embodiment, the post-processing step **S1705** maps outlying color points using a compression method, such as, for example, knee-point compression, or any other suitable type of compression process.

In step **S1706**, the gamut mapped colors are converted to a destination device dependent color space. Through a process similar to that described above in reference to FIG. **5**, gamut-mapped colors which are in a device independent color appearance space are mapped to counterpart colors in a device independent space. The colors in device independent color space are transformed into counterpart colors in the destination device dependent color space using a destination device model of the destination device.

FIG. **18** is a flow diagram for explaining modification step **S1703** of FIG. **17** in more detail. The process steps shown in FIG. **18** are computer-executable process steps stored on a computer-readable memory medium and executed by a CPU of a host computer similar to host computer **41** which is described above with respect to FIG. **3**, so as to modify the source device gamut boundary.

Briefly, according to the process steps shown in FIG. **18**, the source device gamut is shrunk until it touches the image gamut boundary and the source device gamut is further shrunk past the image gamut boundary until a predetermined condition is satisfied.

In more detail, in step **S1801**, the source device gamut boundary is modified by shrinking the source device gamut boundary in a hue symmetric manner, such that hues of colors do not change, until the source device gamut boundary touches the image gamut boundary.

Step **S1802** is an additional shrinking step in which the source device gamut boundary is further shrunk past the image gamut boundary by a predetermined increment. The modification performed in this shrinking step is also performed in a hue symmetric manner.

In step **S1803**, it is determined whether a predetermined condition has been satisfied. If the predetermined condition has not been met, the process returns to step **S1802** in which the source device gamut is further shrunk past the image gamut boundary by the predetermined increment. If the predetermined condition has been met, the modification of the source device gamut boundary ends.

In the third embodiment, the predetermined condition is selected by a user using a graphical user interface which

provides a preview of an image resulting from the selected predetermined condition. In other embodiments, other types of user interfaces such as a command line interface or any other suitable type of user interface can be used. A user can adjust the predetermined condition and preview the result until the user is satisfied. For example, a user can examine an image histogram to estimate the overall impact of a particular condition and dynamically adjust the condition to achieve the desired result. If this previewing process is repeated on a plurality of images, a selection of parameters could be determined which results in optimal color reproduction for a majority of images.

The predetermined condition is determined based on a selection of techniques used to perform the additional shrinking step. The predetermined condition is based on parameters specified for the selected techniques, which are specified by the user via the graphical user interface. For example, a user can select a variety of techniques including a percentage technique, a threshold technique, a distance technique, a destination technique, or any other suitable technique to determine how many outlying color points would be permitted and how far from the modified source device gamut boundary they would be allowed. In particular, a percentage technique involves shrinking the modified source device gamut boundary until a specified percentage of color points of the device independent image lie outside of the modified source device gamut boundary. A threshold technique involves shrinking the modified source device gamut boundary until a specified threshold number of color points of the device independent image lie outside of the modified source device gamut boundary. A distance technique involves shrinking the modified source device gamut boundary until a distance between the modified source device gamut boundary and any color point of the device independent image that lies outside of the modified source device gamut boundary reaches a specified maximum distance. A destination technique involves shrinking the modified source device gamut boundary until the modified source device gamut boundary touches the destination device gamut boundary.

In another embodiment, the additional shrinking step S**1802** and the post-processing step S**1705** are selectively enabled by the user via the user interface.

FIG. **19** is a view for explaining further shrinking of a source device gamut boundary past the image gamut boundary leaving outlying color points according to the third example embodiment. As shown in FIG. **19**, when source device gamut boundary **1902** is further shrunk past image gamut boundary **1903**, one or more color points that lie within image gamut boundary **1903** now lie outside modified source device gamut boundary **1901**. As shown in FIG. **19**, these outlying color points are included in shaded regions **1904**. The outlying color points in region **1904** will lie outside of destination device gamut boundary **1900** after the compression-type GMA performs gamut mapping. The post-processing step S**1705** of FIG. **17** is performed on these outlying color points to convert them into color points that lie on or within destination device gamut boundary **1900**.

This disclosure has provided a detailed description with respect to particular representative embodiments. It is understood that the scope of the appended claims is not limited to the above-described embodiments and that various changes and modifications may be made without departing from the scope of the claims.

What is claimed is:

1. A color management method which converts a source-side color in a source device dependent color space into a counterpart destination-side color in a destination device dependent color space, said method comprising:

obtaining a device independent source device gamut boundary for a source device and a device independent destination device gamut boundary for a destination device;

obtaining a source color image in the source device dependent color space;

transforming the source color image into a device independent image in a device independent color space;

generating an image gamut boundary for the device independent image corresponding to the transformed source color image, based on the color content of the device independent image;

modifying the source device gamut boundary by shrinking the source device gamut boundary in a hue symmetric manner, such that hues of colors do not change, until it touches the image gamut boundary; and

mapping colors of the device independent image onto a gamut of the destination device by invoking a compression-type gamut mapping algorithm that uses the modified source device gamut boundary and the destination device gamut boundary to perform gamut mapping,

wherein the gamut mapped colors are converted into destination-side colors in the destination device dependent color space.

2. The method of claim **1**, further comprising obtaining an intent of the compression-type gamut mapping algorithm,

wherein the source device gamut boundary is shrunk according to the intent of the compression-type gamut mapping algorithm.

3. The method of claim **2**, further comprising determining a compression point, based on the obtained intent of the compression-type gamut mapping algorithm, wherein the source device gamut boundary is modified by moving each point on the source device gamut boundary toward the compression point, until a point on the modified source device gamut boundary touches the image gamut boundary.

4. The method of claim **1**, further comprising, responsive to a determination that the compression-type gamut mapping algorithm performs lightness scaling:

scaling a lightness of the source device gamut boundary so that maximum and minimum values of the lightness of the source device gamut boundary match maximum and minimum values of a lightness of the destination device gamut boundary,

wherein the lightness-scaled source device gamut boundary is shrunk in the modifying step such that only chroma components of the source device gamut boundary are modified,

wherein the modified lightness-scaled source device gamut boundary is re-scaled to an original lightness, and

wherein the re-scaled source device gamut boundary is used by the compression-type gamut mapping algorithm.

5. The method of claim **4**, wherein the lightness-scaled source device gamut boundary is in a color space having at least a coordinate representing lightness and a coordinate representing chroma, and wherein the lightness-scaled source device gamut boundary is modified by moving a chroma component of each point on the lightness-scaled source device gamut boundary toward an axis representing the lightness coordinate, until a point on the modified source device gamut boundary touches the image gamut boundary.

6. The method of claim 1, further comprising an additional shrinking step of further shrinking the source device gamut boundary past the image gamut boundary until a predetermined condition is satisfied.

7. The method of claim 6, wherein the predetermined condition is based on a percentage of color points of the device independent image that lie outside of the modified source device gamut boundary.

8. The method of claim 6, wherein the predetermined condition is based on a threshold number of color points of the device independent image that lie outside of the modified source device gamut boundary.

9. The method of claim 6, wherein the predetermined condition is based on a maximum distance between a color point of the device independent image that lies outside of the modified source device gamut boundary, and the modified source device gamut boundary.

10. The method of claim 6, wherein the predetermined condition is satisfied when the modified source device gamut boundary touches the destination device gamut boundary.

11. The method of claim 6, wherein the predetermined condition is selected by a user.

12. The method of claim 6, wherein the predetermined condition is selected using a graphical user interface, and

wherein the graphical user interface provides a preview of a resulting image.

13. The method of claim 6, wherein after performing the additional shrinking step, one or more color points of the device independent image lie outside the modified source device gamut boundary,

wherein the outlying color points of the device independent image that lie outside the modified source device gamut boundary lie outside the destination device gamut boundary after the compression-type gamut mapping algorithm performs gamut mapping, and

wherein post-processing is performed to convert the outlying color points into color points that lie within the destination device gamut boundary.

14. The method of claim 13, wherein the post-processing step comprises clipping the outlying color points that lie outside of the destination device gamut boundary to a nearest color point on the destination device gamut boundary.

15. The method of claim 13, wherein a compression method is performed in the post-processing step.

16. A color management module stored on a non-transitory computer-readable memory medium which when executed by at least one processor causes the at least one processor to convert a source-side color in a source device dependent color space into a counterpart destination-side color in a destination device dependent color space, said color management module comprising:

an obtaining module constructed to obtain a device independent source device gamut boundary for a source device and a device independent destination device gamut boundary for a destination device;

an image obtaining module constructed to obtain a source color image in the source device dependent color space;

a transforming module constructed to transform the source color image into a device independent image in a device independent color space;

a gamut boundary generating module constructed to generate an image gamut boundary for the device independent image corresponding to the transformed source color image, based on color content of the device independent image;

a modifying module constructed to modify the source device gamut boundary by shrinking the source device gamut boundary in a hue symmetric manner, such that hues of colors do not change, until it touches the image gamut boundary; and

a mapping module constructed to map colors of the device independent image onto a gamut of the destination device by invoking a compression-type gamut mapping algorithm that uses the modified source device gamut boundary and the destination device dependent gamut boundary to perform gamut mapping,

wherein the gamut mapped colors are converted into destination-side colors in the destination device dependent color space.

17. The color management module of claim 16, further comprising an intent obtaining module constructed to obtain an intent of the compression-type gamut mapping algorithm,

wherein the source device gamut boundary is shrunk according to the intent of the compression-type gamut mapping algorithm.

18. The color management module of claim 17, further comprising a determining module constructed to determine a compression point, based on the obtained intent of the compression-type gamut mapping algorithm, wherein the source device gamut boundary is modified by moving each point on the source device gamut boundary toward the compression point, until a point on the modified source device gamut boundary touches the image gamut boundary.

19. The color management module of claim 16, further comprising:

a scaling module constructed to scale a lightness of the source device gamut boundary, responsive to a determination that the compression-type gamut mapping algorithm performs lightness scaling, so that maximum and minimum values of the lightness of the source device gamut boundary match maximum and minimum values of a lightness of the destination device gamut boundary, wherein the lightness-scaled source device gamut boundary is shrunk by the modifying module such that only chroma components of the source device gamut boundary are modified,

wherein the modified lightness-scaled source device gamut boundary is re-scaled to an original lightness, and

wherein the re-scaled source device gamut boundary is used by the compression-type gamut mapping algorithm.

20. The color management module of claim 19, wherein the lightness-scaled source device gamut boundary is in a color space having at least a coordinate representing lightness and a coordinate representing chroma, and wherein the lightness-scaled source device gamut boundary is modified by moving a chroma component of each point on the lightness-scaled source device gamut boundary toward an axis representing the lightness coordinate, until a point on the modified source device gamut boundary touches the image gamut boundary.

21. The color management module of claim 16, further comprising an additional shrinking module constructed to further shrink the source device gamut boundary past the image gamut boundary until a predetermined condition is satisfied.

22. The color management module of claim 21, wherein the predetermined condition is based on a percentage of color points of the device independent image that lie outside of the modified source device gamut boundary.

23. The color management module of claim 21, wherein the predetermined condition is based on a threshold number of color points of the device independent image that lie outside of the modified source device gamut boundary.

24. The color management module of claim **21**, wherein the predetermined condition is based on a maximum distance between a color point of the device independent image that lies outside of the modified source device gamut boundary, and the modified source device gamut boundary.

25. The color management module of claim **21**, wherein the predetermined condition is satisfied when the modified source device gamut boundary touches the destination device gamut boundary.

26. The color management module of claim **21**, wherein the predetermined condition is selected by a user.

27. The color management module of claim **21**, wherein the predetermined condition is selected using a graphical user interface, and

wherein the graphical user interface provides a preview of a resulting image.

28. The color management module of claim **21**, further comprising a post-processing module constructed to process color points of the device independent image that lie outside the modified source device gamut boundary after the additional shrinking module performs shrinking,

wherein the outlying color points of the device independent image that lie outside the modified source device gamut boundary lie outside the destination device gamut boundary after the compression-type gamut mapping algorithm performs gamut mapping, and

wherein the post-processing module converts the outlying color points into color points that lie within the destination device gamut boundary.

29. The color management module of claim **28**, wherein the post-processing module clips the outlying color points that lie outside of the destination device gamut boundary to a nearest color point on the destination device gamut boundary.

30. The color management module of claim **28**, wherein a compression method is performed by the post-processing module.

31. A color management apparatus comprising:

a computer-readable memory constructed to store computer-executable process steps; and

a processor constructed to execute the computer-executable process steps stored in the memory;

wherein the process steps stored in the memory cause the processor to convert source-side colors in a source device dependent color space into counterpart destination-side colors in a destination device dependent color space, and include computer-executable process steps to:

obtain a device independent source device gamut boundary for a source device and a device independent destination device gamut boundary for a destination device;

obtain a source color image in the source device dependent color space;

transform the source color image into a device independent image in a device independent color space;

generate an image gamut boundary for the device independent image corresponding to the transformed source color image, based on color content of the device independent image;

modify the source device gamut boundary by shrinking the source device gamut boundary in a hue symmetric manner, such that hues of colors do not change, until it touches the image gamut boundary; and

map colors of the device independent image onto a gamut of the destination device by invoking a compression-type gamut mapping algorithm that uses the modified source device gamut boundary and the destination device dependent gamut boundary to perform gamut mapping,

wherein the gamut mapped colors are converted into destination-side colors in the destination device dependent color space.

32. The apparatus of claim **31**, wherein the process steps further include process steps to obtain an intent of the compression-type gamut mapping algorithm,

wherein the source device gamut boundary is shrunk according to the intent of the compression-type gamut mapping algorithm.

33. The apparatus of claim **32**, wherein the process steps further include process steps to determine a compression point, based on the obtained intent of the compression-type gamut mapping algorithm, wherein the source device gamut boundary is modified by moving each point on the source device gamut boundary toward the compression point, until a point on the modified source device gamut boundary touches the image gamut boundary.

34. The apparatus of claim **31**, wherein the process steps further include process steps to, responsive to a determination that the compression-type gamut mapping algorithm performs lightness scaling:

scale a lightness of the source device gamut boundary so that maximum and minimum values of the lightness of the source device gamut boundary match maximum and minimum values of a lightness of the destination device gamut boundary,

wherein the lightness-scaled source device gamut boundary is shrunk in the modifying step such that only chroma components of the source device gamut boundary are modified,

wherein the modified lightness-scaled source device gamut boundary is re-scaled to an original lightness, and

wherein the re-scaled source device gamut boundary is used by the compression-type gamut mapping algorithm.

35. The apparatus of claim **34**, wherein the lightness-scaled source device gamut boundary is in a color space having at least a coordinate representing lightness and a coordinate representing chroma, and wherein the lightness-scaled source device gamut boundary is modified by moving a chroma component of each point on the lightness-scaled source device gamut boundary toward an axis representing the lightness coordinate, until a point on the modified source device gamut boundary touches the image gamut boundary.

36. The apparatus of claim **31**, wherein the process steps further include additional shrinking process steps to further shrink the source device gamut boundary past the image gamut boundary until a predetermined condition is satisfied.

37. The apparatus of claim **36**, wherein the predetermined condition is based on a percentage of color points of the device independent image that lie outside of the modified source device gamut boundary.

38. The apparatus of claim **36**, wherein the predetermined condition is based on a threshold number of color points of the device independent image that lie outside of the modified source device gamut boundary.

39. The apparatus of claim **36**, wherein the predetermined condition is based on a maximum distance between a color point of the device independent image that lies outside of the modified source device gamut boundary, and the modified source device gamut boundary.

40. The apparatus of claim **36**, wherein the predetermined condition is satisfied when the modified source device gamut boundary touches the destination device gamut boundary.

41. The apparatus of claim 36, wherein the predetermined condition is selected by a user.

42. The apparatus of claim 36, wherein the predetermined condition is selected using a graphical user interface, and

wherein the graphical user interface provides preview of a resulting image.

43. The apparatus of claim 36, wherein after the additional shrinking process steps perform shrinking, one or more color points of the device independent image lie outside the modified source device gamut boundary,

wherein the outlying color points of the device independent image that lie outside the modified source device gamut boundary lie outside the destination device gamut boundary after the compression-type gamut mapping algorithm performs gamut mapping, and

wherein post-processing is performed to convert the outlying color points into color points that lie within the destination device gamut boundary.

44. The apparatus of claim 43, wherein post-processing comprises clipping the outlying color points that lie outside of the destination device gamut boundary to a nearest color point on the destination device gamut boundary.

45. The apparatus of claim 43, wherein a compression method is performed during post-processing.

46. A non-transitory computer-readable memory medium on which is stored computer-executable process steps for causing a computer to convert a source-side color in a source device dependent color space into a counterpart destination-side color in a destination device dependent color space, said process steps comprising:

obtaining a device independent source device gamut boundary for a source device and a device independent destination device gamut boundary for a destination device;

obtaining a source color image in the source device dependent color space;

transforming the source color image into a device independent image in a device independent color space;

generating an image gamut boundary for the device independent image corresponding to the transformed source color image, based on the color content of the device independent image;

modifying the source device gamut boundary by shrinking the source device gamut boundary in a hue symmetric manner, such that hues of colors do not change, until it touches the image gamut boundary; and

mapping colors of the device independent image onto a gamut of the destination device by invoking a compression-type gamut mapping algorithm that uses the modified source device gamut boundary and the destination device gamut boundary to perform gamut mapping,

wherein the gamut mapped colors are converted into destination-side colors in the destination device dependent color space.

47. The computer-readable memory medium of claim 46, wherein the process steps further comprise obtaining an intent of the compression-type gamut mapping algorithm,

wherein the source device gamut boundary is shrunk according to the intent of the compression-type gamut mapping algorithm.

48. The computer-readable memory medium of claim 47, wherein the process steps further comprise determining a compression point, based on the obtained intent of the compression-type gamut mapping algorithm, wherein the source device gamut boundary is modified by moving each point on the source device gamut boundary toward the compression point, until a point on the modified source device gamut boundary touches the image gamut boundary.

49. The computer-readable memory medium of claim 46, wherein the process steps further comprise, that the compression-type gamut mapping algorithm performs lightness scaling:

scaling a lightness of the source device gamut boundary so that maximum and minimum values of the lightness of the source device gamut boundary match maximum and minimum values of a lightness of the destination device gamut boundary,

wherein the lightness-scaled source device gamut boundary is shrunk in the modifying step such that only chroma components of the source device gamut boundary are modified,

wherein the modified lightness-scaled source device gamut boundary is re-scaled to an original lightness, and

wherein the re-scaled source device gamut boundary is used by the compression-type gamut mapping algorithm.

50. The computer-readable memory medium of claim 49, wherein the lightness-scaled source device gamut boundary is in a color space having at least a coordinate representing lightness and a coordinate representing chroma, and wherein the lightness-scaled source device gamut boundary is modified by moving a chroma component of each point on the lightness-scaled source device gamut boundary toward an axis representing the lightness coordinate, until a point on the modified source device gamut boundary touches the image gamut boundary.

51. The computer-readable memory medium of claim 46, wherein the process steps comprise an additional shrinking step of further shrinking the source device gamut boundary past the image gamut boundary until a predetermined condition is satisfied.

52. The computer-readable memory medium of claim 51, wherein the predetermined condition is based on a percentage of color points of the device independent image that lie outside of the modified source device gamut boundary.

53. The computer-readable memory medium of claim 51, wherein the predetermined condition is based on a threshold number of color points of the device independent image that lie outside of the modified source device gamut boundary.

54. The computer-readable memory medium of claim 51, wherein the predetermined condition is based on a maximum distance between a color point of the device independent image that lies outside of the modified source device gamut boundary, and the modified source device gamut boundary.

55. The computer-readable memory medium of claim 51, wherein the predetermined condition is satisfied when the modified source device gamut boundary touches the destination device gamut boundary.

56. The computer-readable memory medium of claim 51, wherein the predetermined condition is selected by a user.

57. The computer-readable memory medium of claim 51, wherein the predetermined condition is selected using a graphical user interface, and

wherein the graphical user interface provides a preview of a resulting image.

58. The computer-readable memory medium of claim 51, wherein after performing the additional shrinking step, one or more color points of the device independent image lie outside the modified source device gamut boundary,

wherein the outlying color points of the device independent image that lie outside the modified source device gamut boundary lie outside the destination device gamut

boundary after the compression-type gamut mapping algorithm performs gamut mapping, and

wherein post-processing is performed to convert the outlying color points into color points that lie within the destination device gamut boundary.

59. The computer-readable memory medium of claim **58**, wherein the post-processing step comprises clipping the outlying color points that lie outside of the destination device gamut boundary to a nearest color point on the destination device gamut boundary.

60. The computer-readable memory medium of claim **58**, wherein a compression method is performed in the post-processing step.

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